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RESEARCH TO DETERMINE FAILURE

MODES FOR TRANSISTORS

CONTRACT NAS 8-11059

QUARTERLY REPORT NO. 2

JANUARY THROUGH MARCH 1964

GENERAL ELECTRIC COMPANY

SEMICONDUCTOR PRODUCTS DEPART.

SYRACUSE, N. Y.

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RESEARCH TO DETERMINE FAILURE MODES

FOR TRANSISTORS

SECOND QUARTERLY REPORT

JANUARY - MARCH 1964

OBJECT: Study of failure modes and screening techniques to eliminate potential failures of silicon planar transistors manufactured by three separate processes to the 2N718A specification.

Process A - Double diffused, with Au to Al contacts.

Process B - Double diffused, epitaxial with AL to Al contacts.

Process C - Triple diffused, with Au to Al contacts.

Abstract -

This report is preliminary, giving results of an initial stress response survey made to clarify and adjust procedures for a large scale.

Investigation was made of failures by:

1. A step stress matrix of temperature, temperature plus voltage, and power for four steps and 100 and 500 hour tread lengths.
2. Step stress of centrifuge to 150 KG.
3. Vibration - Shock and Shock - Vibration.
4. Noise current measurements at 5 micro-amperes, 100 cycle, 1,000 cycle and 10,000 cycle and 30 ma at 1,000 cycle.

Techniques for screening to noise limits are reviewed together with some indication that a noise screen can be used to decrease the percentage failure of some individual types of failure.

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1.0 Purpose of the Project

The purpose of the project is to determine the failure modes for transistors manufactured by three different processes.

From this study a specific screening method will be established and tested so as to learn all possible factors necessary to screen transistors to improve failure rates.

1.1 Details Covered in this Report

This report essentially covers the complete results of Phase I of the experiment and provides some preliminary information on Phase II.

Phase I consists of a 6 X 4 step stress matrix electrical experiment showing the effects of temperature alone and temperature plus voltage. In addition, a 4 step centrifuge experiment and a two-step shock vibration and a vibration shock experiment were covered. This experiment was designed to use a small sample and provide all possible basic factors necessary to fin alize a large sample matrix experiment to test the screening methods.

1.2 Matrix Details

Fig. 1.2.1 covers the matrix details of the experiment completely.

1.3 This report covers the following:

1. Status of the project.

2. Comparative results of the step stress experiment.

3. Failure analysis of representative devices.

4. Preliminary results of the noise investigation.

5. Preliminary review of phase II.

6. Modifications to the project.

7. Conclusions possible from results to date.

1.4 Status of the Project

The progress to date is about two weeks behind the original schedule proposed in October Letter Report. Delay has been caused by the un-expected work load on the noise test equipment and by an un-anticipated increase in the data editing and verification procedure.

Both procedures are producing sufficient valuable additions to the original intent of the project that the delay is well justified. The data editing and noise testing are hand testing operations and can only be done by a single skilled worker at a time.

Status of Phase II on March 31 shows completion of all tests to the centrafuge test of all units.

NASA CONTRACT
INITIAL STRESS

ITEM	TEST EQUIPT.	1963 WEEK 44	45	46	47	48	49	50	51	52	1964 WEEK 1	2	3	4	5	6	7	8
1. TEMP.STRESS - 100 hrs. 30 UNITS * 343201			250°C	Read & Store		300°C	Read & Store		340°C	Read & Store		380°C	Read					
2. TEMP.STRESS - 500 hrs. 30 UNITS * 343202			250°C			Read 300°C			Read 340°C			Read 380°C			Read			
3. TEMP. & VOLTAGE - 100 hrs. 30 UNITS * 343203			30V 250°C	Read & Store		30V 300°C	Read & Store		30V 340°C	Read & Store		30V 380°C	Read					
4. TEMP. & VOLTAGE - 500 hrs. 30 UNITS * 343204			30V 250°C			Read 30V 300°C			Read 30V 340°C			Read 30V 380°C			Read			
5. POWER STEP STRESS 30 UNITS * 343205	INLAND & QUANTEC	INITIAL READING	20V 500 mw	Read & Store		20V 670mw	Read & Store		20V 830 mw	Read & Store		20V 1000 mw	Read					
6. POWER STEP STRESS 30 UNITS * 343206			20V 500 mw			Read 20V 670 mw			Read 20V 830 mw			Read 20V 1000 mw			Read			
7. CENTRIFUGE 30 UNITS * 343207			Y_1X_2 20 KG	Read	Y_1X_2 50 KG	Read	Y_1X_2 100 KG	Read	Y_1X_2 150 KG	Read								
8. SHOCK - VIBRATION 30 UNITS * 343208			SHOCK	Read	VIB.	Read												
9. VIB. - SHOCK 30 UNITS * 343209			VIB.	Read	SHOCK	Read												
1530 UNITS *		RADIFLO (10^{-10})														BEGIN TEMP SCREEN		

NOTE: At each measurement point, units will be read on both the Inland and the Quantec equipment.

* All samples are composed of equal parts of Process A, B and C units.

FIG. 1.2.1

1.5 Brief Outline of the results

1. Dominant modes of failure for each of the three processes were determined and found to differ both in the percentage included in the distribution and in nature of the failure caused.

2. In general, time dependency of the experiments shows a 5/2 relationship (5X time produces 2X failures). This varies somewhat with stress and with process.

3. The acceleration factor appropriate to estimate failures by use of temperature as a substitute for time, varies with process.

4. Noise can be used as a screen to eliminate potential failures but the relation between test limit and failure rate improvement varies with process and with measurement conditions.

5. Noise is generated by mechanisms which are related to degradation and by mechanisms which are not related to degradation. As a result, screening to a noise limit can decrease reliability as well as increase reliability.

6. The degradation associated noise mechanism becomes more active with usage of the transistor. Testing after an electrical stress will be more effective than testing a new transistor.

7. Dominate failure modes were found to be:

   Process A Collector Base Surface Degradation
   Process B Lead Bond Failure at Post
   Process C Collector Base Bulk Degradation

8. The experiment as now planned should show a significant improvement in the reliability of each of the 3 processes when submitted to the planned screening procedure.

2.0 Results of the Matrix Experiment

Details of the step stress experiment and the numbers of failures for each type of stress are shown in Section 2 as follows:

2.1 Temperature Stress
2.2 Temperature plus Voltage
2.3 Power Stress
2.4 Mechanical Step Stress
2.5 Conclusions

2.1 The Effect of Temperature Stresses

10 units from each process were submitted to a 4 step 100 hour tread step stress test at 250 C, 300 C, 340 C, and 380 C, lot number 343201. These temperature levels were intended to produce failure rates < 10, 10-50, 50-9, and >90% Another 10 units from each process were submitted to the same stresses for 500 hours on each tread.

FIGURE 2.1.1

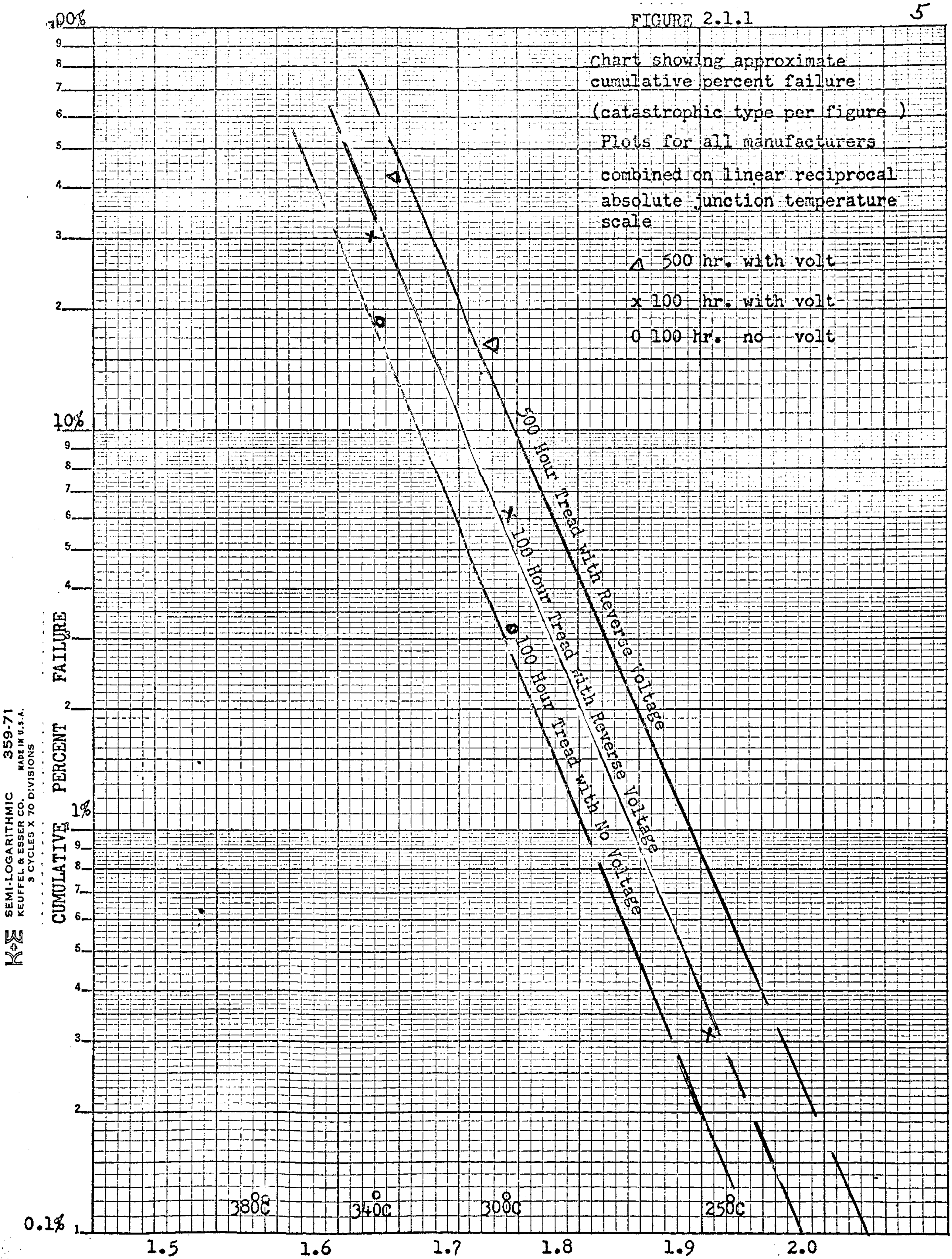


Chart showing approximate cumulative percent failure (catastrophic type per figure)
Plots for all manufacturers combined on linear reciprocal absolute junction temperature scale
△ 500 hr. with volt
x 100 hr. with volt
0 100 hr. no volt
500 Hour Tread with Reverse Voltage
100 Hour Tread with Reverse Voltage
100 Hour Tread with No Voltage
CUMULATIVE PERCENT FAILURE
100%
10%
1%
0.1%
380°C
340°C
300°C
250°C
1.5
1.6
1.7
1.8
1.9
2.0
SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

2.1.1 Fig. 2.1.1 is an approximate Arrhenius plot of the results obtained on the combination of all three processes.

The data is only a rough approximation, but tends to indicate that 500 hours does not produce a 5 to 1 increase in failures. This supports the assumptions made in the screening experiment where weak units are expected to fail early.

This curve also shows the approximate relation between temperature and failure rate.

The initial estimate of 380°C for the upper limit or 100% failure with temperatures was confirmed by step 4.

Fig. 2.1.2 and 2.3.3 show the tabulated values of I_{CBO} for the combined lots (Process A + B + C).

The use of Al - Al contact system did not improve operation above 380 C (Gold Melting Point).

This was due to use of gold to mount this header and use of gold bonding at the post.

2.1.2 Fig. 2.1.2 shows the tabulated distribution of values for ICBO for the combined 3 processes at the 100 hour tread length.

2.1.3 Fig. 2.1.3 shows the same distribution for the 500 hour tread.

Examination of this shows little clear distinction between the 100 hour and 500 hour treads for most units. About 10% of units show a greater degradation on the 500 hour tread.

Small sample size may be the reason for the small percentage change. This was below the expected percentage and will require the larger sample size of later phases to make conclusions.

Fig. 2.1.4 is a table showing the cumulative catastrophic failure count for the 3 processes individually with the 100 hour and 500 hour results compared.

DATA ANALYSIS SUMMARY OF THE INITIAL STRESS RESPONSE SURVEY

(ALL PROCESSES COMBINED)

FIGURE . . . CHARACTERISTICS OF PARAMETER DISTRIBUTION

EXPERIMENT: Temperature Step Stress - 100 hr. Tread Step
CELL: #343201
CYCLE = None

OPERATING CONDITIONS: T_J = stepped As shown °C.; T_A = stepped As shown °C.; V_{CB} = 0 V.;

SPECIAL CONDITIONS:
PARAMETER: I CBO
BIAS CONDITIONS: VCB = 60V

UNITS: Percentiles of ICBO in Nanoamperes (10-9 AMP) unless otherwise indicated and cumulative failure count below A or several levels of failure

NO.	UNITS STARTING =	30 Randomly chosen devices - 10 units per Process								
	STEP LEVEL =	Initial	250°C	300°C	340°C	380°C				
1	MINIMUM	0.1	0.1	0.1	0.1					
2	5 PERCENTILE	0.1	0.1	0.1	0.1					
3	10 PERCENTILE	0.1	0.1	0.1	0.1					
4	1st QUARTILE	0.4	0.2	0.4	0.6					
5	MEDIAN	0.7	0.7	1.3	1.2	DESTRUCTIVE STRESS LEVEL				
6	3rd QUARTILE	1.3	1.4	14.0	590.0					
7	90 PERCENTILE	2.8	6.5	5.5μa	6.1μa					
8	95 PERCENTILE	3.1	100.0	11.6μa	15.0μa					
9	MAXIMUM	3.2	150.0	17.0μa	17.0μa					
10	CUMULATIVE NO. EXCEEDING 1μa	0	0	5 (all C)	7 (all C)					
11	0.1μa	0	1 (C)	5 "	8 (7C 1B)					
12	0.05μa	0	(1B 1C)	6 (5C 1B)	9 (8C 1B)					
13	0.01μa	0	2 "	8 (6C 2B)	11 (9C 2B)					

Fig. 2.1.2

DATA ANALYSIS

ALL PROCESSES COMBINED

FIGURE . . . CHARACTERISTICS OF PARAMETER DISTRIBUTION

EXPERIMENT: Temperature Step Stress - 500 hr Tread/Ste

CELL: #343202

CYCLE = None

OPERATING CONDITIONS: T_J = stepped as shown °C.; T_A = stepped as shown °C.; V_{CB} = 0 V.;

PECIAL CONDITIONS:

PARAMETER ICBO

UNITS: PERCENTILES OF ICBO IN NANOAMPERES (10-9 AMP) UNLESS OTHERWISE INDICATED AND CUMULATIVE FAILURE COUNT BELOW FOR SEVERAL LEVELS OF FAILURE

BIAS CONDITIONS: VCB = 60V

NO. UNITS STARTING = 30 Randomly chosen Devices - 10 Units per

	STEP LEVEL =	Initial	250°C	300°C	340°C	380°C						
1	MINIMUM	0.1	0.1	0.1	0.1							
2	5 PERCENTILE	0.2	0.1	0.1	0.1							
3	10 PERCENTILE	0.2	0.1	0.2	0.1							
4	1st QUARTILE	0.2	0.1	0.4	0.4							
5	MEDIAN	0.6	0.4	0.7	0.9							
6	3rd QUARTILE	1.5	1.0	1.3	140.5	DESTRUCTIVE STRESS LEVEL						
7	90 PERCENTILE	2.5	2.3	65.0µa	87.7µa							
8	95 PERCENTILE	2.6	2.7	≥100µa	100µa							
9	MAXIMUM	2.6	2.8	≥100µa	100µa							
10	CUMULATIVE NO. EXCEEDING 1µa	0	0	4 (all 3)	6 (all 3)							
11	0.1µa	0	0	4 "	6 "							
12	0.05µa	0	0	4 "	7 "							
13	0.01µa	0	0	5 "	9 (8c 1A)							

Does not Include

1 open (B type) Base
1 collector-emitter short (C type)

2 open (B type) Base
2 collector-Emitter short (C Type)

Does not include

Fig. 2.1.3

Fig. 2.1.4

CUMULATIVE CATASTROPHIC FAILURE COUNT SUMMARY FOR EACH STEP STRESS CELL PER MANUFACTURER UNITS OPEN, SHORTED, ETC.

(10 Devices Per Process Starting)

Temperature Step Stress With No Reverse Collector Voltage

	100 Hour Duration Per Step Cell #343201				500 Hour Duration Per Step Cell #343202			
rocess	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Step	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Ste
A	0	0	1	All Catastrophic (predominately C_2 Type)	0	0	0	All Catastrophic (predominately C_2 type)
B	0	0	1		0	1(C_2 Type)	Both 2(C_2 Type)	
C	0	1(Cl Type)	(ac_1 type) 4(ac_2 type)		0	All 4(C_1 Type)	All 5(C_1 Type	

The one catastrophic failure or 100 hour for Process A is inconsistant with no failures on 500 hour tread.

Otherwise, the over-all catastrophic failure count does indicate that time is important in Process B and C.

Process C does show much more response to time than to temperature as indicated by 4 failures at 500 hour 300 C instead of 1 at the 100 hour test.

Sample size is much too small to make definite conclusions.

Fig. 2.1.5

CUMULATIVE LEAKAGE DEGRADATION FAILURE COUNT SUMMARY FOR EACH STEP STRESS CELL PER PROCESS

(10 Devices Per Process Starting)

Temperature Step Stress With No Reverse Collector Voltage

	100 Hour Duration Per Step Cell #343201				500 Hour Duration Per Step Cell #343202			
ocess	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Step	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Step
A	0	0	0	Destructive Level	0	0	0	Destructive Level
B	0	0	0		0	0	0	
C	0	2	5		0	4	8	

Fig. 2.1.5 shows the cumulative failures separated by Process.

A failure is here defined as I_{CBO} greater than 10 microampers, I_{CEO} 10 micro amperes.

Units from Process C contributed all failures of the high leakage type.

Temperature and time both are effective but 500 hours does not produce 5X the failure rate.

2.2 Effects of Temperature plus Voltage

2.2.1 The addition of voltage to the temperature as shown by experiment 343203 and 343204 shows a substantial increase in the median readings and higher percentiles as shown by comparison of 2.2.1 and 2.1.2 tables of I_{CBO} distributions. Fig. 2.2.2 shows 500 hour temperature plus voltage readings. This is also higher than indicated in the upper 10th percentiles and above.

2.2.3 Catastrophic Failure Count by individual processes is shown in Fig. 2.2.3. Failures began at 250 C in the Process C and almost doubled due to the 500 Hour over the 100 hour step.

A rough estimate of 5X time produces 2X failures. This within the restriction of the small sample size seems applicable to any of the 3 processes or all combined as shown in 2.1.1.

Fig. 2.2.3

Temperature Step Stress With Fixed 30V Reverse Collector Voltage

	100 Hour Duration Per Step Cell #343203				500 Hour Duration Per Step Cell #343204			
ocess	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Step	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Step
A	0	0	0	All Catastrophic (predominately C_2 type)	0	1(C_2 Type)	both 2(C_2 type)	All Catastrophic (predominately C2 type)
B	0	0	All 5(C_2 Type)		0	1(C_2 Type)	All 5(C_2 Type)	
C	1(C_1 Type)	(1 C_1 Type) 2(1 C_2 Type)	(4 C_2 Type) 5(1 C_1 Type)		1(C_1 Type)	(2 C1 Type) 3(1 C_2 Type)	(4 C_1 Type) 9(5 C_2 Type)	

Fig. 2.2.4 Cumulative Leakage Failures by Process

Temperature Step Stress With Fixed 30V Reverse Collector Voltage

	100 Hour Duration Per Step Cell #343203				500 Hour Duration Per Step Cell #343204			
ocess	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Step	250 C First Step	300 C Second Step	340 C Third Step	380 C Final Step
A	0	0	0	Destructive Level	0	0	4	Destructive Level
B	0	1	2		0	0	4	
C	2	3	8		2	5	10	

DATA ANALYSIS SUMMARY OF THE INITIAL STRESS RESPONSE SURVEY

(ALL PROCESSES COMBINED)

FIGURE . . CHARACTERISTICS OF PARAMETER DISTRIBUTION

EXPERIMENT: Temperature Step Stress with Fixed collector voltage of 30V-100hr.Tread/Ste

CELL: #343203

CYCLE = None

OPERATING CONDITIONS: T_J = ~~as shown~~ stepped as shown °C.; T_A = stepped as ~~shown~~ °C.; V_{CB} = 30 V.;

SPECIAL CONDITIONS:

PARAMETER: ICBO

UNITS: PERCENTILES OF ICBO in Nanoampers (10-9 AMP) unless otherwise indicated and cumulative failure count below A of several levels of failure

BIAS CONDITIONS: VCB = 60V

NO. UNITS STARTING = 30 Randomly chosen devices - 10 units per Process

NO.	STEP LEVEL =	Initial	250°C	300°C	340°C	380°C
1	MINIMUM	0.1	0.1	0.6	0.1	
2	5 PERCENTILE	0.1	0.1	0.7	0.1	
3	10 PERCENTILE	0.2	0.1	0.8	0.2	
4	1st QUARTILE	0.3	0.7	1.7	0.8	
5	MEDIAN	0.8	1.6	6.1	3.1	
6	3rd QUARTILE	3.1	4.0	394.6	8.2μa	
7	90 PERCENTILE	4.6	2.9μa	7.0μa	24.9 μa	
8	95 PERCENTILE	9.7	3.2μa	25.8μa	85.0μa	
9	MAXIMUM	15.9	3.2μa	31.0μa	90.0μa	
10	CUMULATIVE NO. EXCEEDING 1μa	0	3 (all C)	8 (7C 1B)	11 (9C 2B)	
11	0.1μa	0	5 (all C)	10 (8C 2B)	13 (10C 2B 1A)	
12	0.05μa	0	5 "	11 (9C 2B)	13 "	
13	0.01μa	1 (C)	5 "	14 (10C 3B 1A)	14 (10C 2B 2A)	

Does not include 3 out-of-range sat/Beta for B Type

FIG. 2.2.1

DATA ANALYSIS SUMMARY OF THE INITIAL STRESS RESPONSE SURVEY

(ALL PROCESSES COMBINED)

FIGURE . . . CHARACTERISTICS OF PARAMETER DISTRIBUTION

EXPERIMENT: Temperature Step Stress With Fixed Collector voltage of 30V-500hr Tread/Step

CELL: #343204

CYCLE = None

OPERATING CONDITIONS: T_J = stepped as shown °C.; T_A = stepped as shown °C.; V_{CB} = 30 V.;

SPECIAL CONDITIONS:

PARAMETER: ICBO

BIAS CONDITIONS: VCB = 60V

UNITS: PENCENTILES OF ICBO IN NANOAMPERS (10-9 AMP UNLESS OTHERWISE INDICATED AND CUMULATIVE FAILURE COUNT BELOW A OF SEVERAL LEVELS OF FAILURE

NO.	UNITS STARTING =	30 Randomly chosen devices - 10 units per Process								
	STEP LEVEL =	Initial	250°C	300°C	340°C	380°C					
1	MINIMUM	0.2	0.1	0.3	0.3						
2	5 PERCENTILE	0.2	0.1	0.4	0.5						
3	10 PERCENTILE	0.2	0.1	0.5	1.1						
4	1st QUARTILE	0.4	0.3	0.7	17.7						
5	MEDIAN	0.7	1.5	2.3	695.5						
6	3rd QUARTILE	2.3	11.6	246.2	61.0μa						
7	90 PERCENTILE	3.5	678.7	18.2μa	>100μa	DESTRUCTIVE STRESS LEVEL					
8	95 PERCENTILE	4.0	2.0μa	58.0μa	> 100μa						
9	MAXIMUM	4.3	2.7μa	88.0μa	> 100μa						
10	CUMULATIVE NO. EXCEEDING 1μa	0	2 (all C)	4 (all C)	14 (8C 3A 3B)						
11	0.1μa	0	5 (all C)	8 (all C)	20 (9C 6A 5B)						
12	0.05μa	0	5 "	8 "	21 (9C 6A 6B)						
13	0.01μa	0	7 "	11 (9C 2A)	23 (9C 7A 7B)						

300°C: Does not include 1 Sat/Betha out of Range (B Type)

340°C: Does Not include 2 opens (1 B Type) (1 C Type)

Fig. 2.2.2

2.3 Failures due to Power Stress

Failures due to power stress appeared considerably below that which could be expected on the basis of failures due to temperature or temperatures plus voltage.

From the rated thermal resistivity of the 2N718A specification, 4 watts or 437 C/watt, the junction temperature would be 462 C for the 1,000 mw dissipation level.

The rating as specified on the 2N718A is so over conservative that a transistor operated at the 1,000 mw level would be operating far in excess of destructive levels.

The 1,000 mw level, however, shows very acceptable performance due to a much lower actual thermal resistance.

This illustrates one of the dangers of using specification values which were consistently improved on actual lots of semiconductors produced.

2.3.1 Thermal resistivity measured values.

Junction Temperature at different power levels

PROCESS	RESISTIVITY	500 mw	670	830	1000
A	276°C/w	163 C	210	255	301
B	284	167	211	261	309
C	286	168	217	262	311

2.3.2 The distribution of I_{CBO} for the 100 hour and 500 hour tread (2.2.1 and 2.2.2) show reasonable comparison of the distrubution for 300 C temperature plus voltage.

These values are shown on 2.3.2.1 and 2.3.2.2.

2.3.3 Catastrophic failure count by individual processes as shown in Fig. 2.3.3

When catastrophic failures are counted instead of shift in the median values, power stress produces a substantially higher failure than would be expected from thermal resistivity.

Catastrophic failures of 830 mw compares with failures at 300°C with combined temperatures and voltage.

This can be attributed to the 311-311 C/w thermal resistivity being an average value and many of the units would have higher thermal resistivities causing a percentage of units operating at a junction temperature substantially above the 311°C.

DATA ANALYSIS SUMMARY OF THE INITIAL STRESS RESPONSE SURVEY
(ALL PROCESSES COMBINED)

FIGURE . . CHARACTERISTICS OF PARAMETER DISTRIBUTION

EXPERIMENT: Power Step Stress Room Ambient
Fixed collector voltage of 20V
~~100 Hour Trend/Step~~

CELL: #343205

CYCLE = None

OPERATING CONDITIONS: T_J = stepped as ~~shown~~ °C.; T_A = 25 °C.; V_{CB} = 0 V.;

SPECIAL CONDITIONS:

PARAMETER: ICBO

UNITS: PERCENTILES OF ICBO IN NANOAMPERS (10-9) AMP UNLESS OTHERWISE INDICATED AND CUMULATIVE FAILURE COUNT BELOW A OF SEVERAL LEVELS OF FAILURE

BIAS CONDITIONS: VCB = 60B

NO. UNITS STARTING = 30 Randomly chosen devices - 10 units per Process

NO.	STEP LEVEL =	Initial	500 mw	670mw	830 mw	1000 mw
1	MINIMUM	0.2	0.1	0.1	0.1	0.1
2	5 PERCENTILE	0.2	0.1	0.1	0.1	0.2
3	10 PERCENTILE	0.2	0.1	0.1	0.1	0.5
4	1st QUARTILE	0.4	0.2	0.4	0.3	0.7
5	MEDIAN	0.9	0.6	0.9	0.7	1.7
6	3rd QUARTILE	1.7	1.4	2.7	2.5	4.1
7	90 PERCENTILE	2.9	2.7	3.9	3.6	30.3
8	95 PERCENTILE	3.2	3.0	193.7	169.9	7.2μa
9	MAXIMUM	3.3	3.3	412.4	357.8	11.8μa
10	CUMULATIVE NO. EXCEEDING 1μa	0	0	0	0	2 (All C)
11	0.1μa	0	0	1 (C)	1 (C)	2 "
12	0.05μa	0	0	1 "	1 "	2 "
13	0.01μa	0	0	2 (1C 1A)	2 (1C 1A)	4 (2C 2A)

Fig. 2.3.1

DATA ANALYSIS SUMMARY OF THE INITIAL STRESS RESPONSE SURVEY

(ALL PROCESSES COMBINED)

FIGURE 1F CHARACTERISTICS OF PARAMETER DISTRIBUTION

EXPERIMENT: Power Step Stress & Room Ambient; ✓ Fixed collector voltage of 20V
CELL: #343206 500 Hr. Tread/Step
CYCLE = None

OPERATING CONDITIONS: T_J = ____ °C.; T_A = 25 °C.; V_{CB} = 20 V.;

SPECIAL CONDITIONS: ____
PARAMETER: ICBO
BIAS CONDITIONS: VCB = 60V

UNITS: PERCENTILES OF ICBO IN NANOAMPER (10-9) AMP UNLESS OTHERWISE INDICATED AND CUMULATIVE FAILURE COUNT BELOW A OF SEVERAL LEVELS OF FAILURE

NO.	UNITS STARTING =	29 Randomly Chosen Units*									
	STEP LEVEL =	Initial	500 mw	670 mw	830 mw	1000 mw					
1	MINIMUM	0.1	0.1	0.1	0.1	0.1					
2	5 PERCENTILE	0.1	0.1	0.1	0.1	0.1					
3	10 PERCENTILE	0.1	0.1	0.2	0.2	0.2					
4	1st QUARTILE	0.4	0.2	0.5	0.9	0.8					
5	MEDIAN	0.7	0.7	1.4	2.6	2.5					
6	3rd QUARTILE	1.5	3.6	5.5	20.0	2.1 μa					
7	90 PERCENTILE	3.9	3[illegible].8	23.5	[illegible]μa	>100μa					
8	95 PERCENTILE	4.2	4.2μa	2.9μa	>100u	>100μa					
9	MAXIMUM	4.2	7.7μa	3.1μa	>100u	>100μa					
10	CUMULATIVE NO. EXCEEDING 1μa	0	1 ( )	2 (1B 1A)	6 (4C 1B 1A)	8 (4C 1B 3A)					
11	0.1μa	0	2 (1B 1A)	3 (1B 2A)	6 "	10 (7C 1B 3A)					
12	0.05μa	0	2 "	3 "	6 "	10 "					
13	0.01μa	0	3 (1B 2A)	4 (2B 2A)	11 (6C 2B 3A)	14 (8C 2B 4A)					

* 1 unit of C type Read 20 μa and is not considered here

Does not include
1 C type
our of range on
Sat/Beth

Fig. 2.3.2

The questions involved do require a more detailed study using the phase II and III larger sample size for comparison and identification of causes.

2.3.3 also shows a time dependency of failures which was not so pronounced on all 3 processes with the other experiment.

Fig. 2.3.3

Room Ambient Power Step Stress With Fixed Collector Voltage 20V

	100 Hour Duration Per Step				500 Hour Duration Per Step			
ocess	500 mw First Step	670 mw Second Step	830 mw Third Step	1000 mw Fourth Step	500 mw First Step	670 mw Second Step	830 mw Third Step	1000 mw Fourth Step
A	0	0	0	0	0	1(C_1 Type)	4(3 C_1 Type) (1 C_2 Type)	6(5 C_1Typ (1 C_2 Typ
B	0	0	0	1 (C_2 Type)	1 (C_2 Type)	1(C_2 Type)	1(C_2 Type)	2(C_2 Type
C	0	0	0	1 (C_2 Type)	0	0	3(2 C_2 Type) (1 C_1 Type)	5(2 C_1Typ (3 C_2Typ

Device parameter characteristics for the C_1 catastrophic failure type for the C_1 catastrophic failure type are extremely degraded or short C-E junction ($BV_{CEO} < 1V$) and/or excessive CB or CE reverse leakage current ($> 100\ \mu a$).

Device parameter characteristics for the C_2 catastrophic failure type are out of range (or approaching such) readings for voltage, saturation and/or I_B readings for dc gain h_{FE}. In many cases these units are open.

2.3.4 Cumulative leakage failures by process

This table shows the cumulative leakage failures by process due to the power step stress. Failure is defined as a unit exceeding 10 uA I_{CBO}.

Failures as indicated by degradation in I_{CBO} follows a pattern similar to those indicated by shorts.

The failures were more severe than indicated by the temperature plus voltage test (Fig. 2.2.4) for process A units and less severe for Process B and C units. This is also an inconsistency which will require re-evaluation with the large sample of phase II and III.

Fig. 2.3.4.1

Room Ambient Power Step Stress With Fixed Collector Voltage - 20V

	100 Hour Duration Per Step Cell #343205				500 Hour Duration Per Step Cell #343206			
rocess	500 mw First Step	670 mw Second Step	830 mw Third Step	1000 mw Final Step	500 mw First Step	670 mw Second Step	830 mw Third Step	1000 mw Final Step
A	0	0	0	0	0	0	2	5
B	0	0	0	0	0	0	0	0
C	0	0	0	1	0	0	3	4

2.4 Effects of Mechanical Step Stress

Three mechanical step stress experiments were made.

In general, information produced was too small for interpretation with any great confidence. The results are shown by results of each individual failure.

2.4.1 Centrifuge Step Stress Test

The centrifuge step stress consisted of lot 343-207 submitted to 20, 50, 100 and 150 kg centrifuge acceleration on the X_1 and Y_2 axis.

Failures occurred to 2 units, both from Process C.

Unit C91 failed at first step (20 KG) open due to broken lead bond. Unit C451 failed at step 3 (100 KG) due to broken lead bond. This unit is shown in photographs para. 3.6.4.2.

Such failures were consistent with the micro cracks found in Process C units.

2.4.2 Lot 343-208 Shock - Vibration Stress Units were given 20 blows of shock of 3000 G .2 m sec on 6 planes. This was followed in step 2 by vibration in each of 6 planes for 10 minutes at 409 1.5 kcps.

Unit No. C485 showed hugh I_{CBO} leakage of end of step 2.

There is no clear understanding if this change was associated with vibration. Similar changes occurred in storage of these units.

2.4.3 Lot 343-209 Vibration - Shock Step Stress

The two steps of 343-208 were reversed in this test to learn if shock would weaken and vibration destroy or if the opposite reaction would occur.

Unit C78 failed high leakage at the initial test. This tends to confirm the conclusion of previous tests. Unit C325 showed high leakage after vibration.

2.4.4 Conclusions

The use of mechanical stress in the levels shown does not cause sufficient damage to be detectable on units other than those that are structually weak.

The more detailed work of phase III may show a small percentage does shift, but this was concealed by the small sample tested.

2.4.5 Work Unfinished

The 3 process C units which failed during or prior to the mechanical stresses will be submitted to the next lot of failure analysis. This may aid in learning if the stress acted to increase the characteristic cracking under lead bonds that was reported as a dominate failure mode in para. 3.8.2.3.

2.5 Conclusions found in Stress Experiment

Phase I of this experiment had a primary purpose of finding any inconsistency in Phase II and III of the program as planned.

The details shown in this report do give some ideas of the final result but are not conclusive in most aspects. The follow-conclusions can be made from the data presently available:

1. The experiment as planned should provide a sound understanding of the merits of the screening method proposed.

2. The chosen stress levels and times should produce adequate failures to provide good confidence in the results.

3. The relation between reliability and failures, to any one fixed set of limits is a complex relationship which is not conclusive when making direct comparison between semiconductors manufactured by different processes.

4. The effect of time varies in each of the three processes and each of the three electrical stresses employed.

5. The acceleration factor due to temperature is not a constant but varies for each of the three processes.

6. Voltage effects differ for each of the 3 processes.

2.6 Future Analysis

1. The differences in 3 processes in response to time and temperature can be due to basic differences in the processes or can be due to the inclusion of different percentages of units containing a particular failure mechanism. Analysis will be conducted on the larger sample sizes to establish this relation.

2.6 Future Analysis (Cont.)

2. Review of preliminary data from Phase II showed an uncontrolled variable which may explain some of the inconsistances. This is the time between temperature stress and test. Process A has been shown to have a substantial difference when tested with a long delay rather than a short delay.

   A supplemental experiment using the mechanical and power test survivors from phase I is being planned to determine the nature of this variable.

3.0 Failure Analysis

3.1 Purpose

This section covers reject analysis and includes a review of the failure analysis procedure. Details of failure mechanisms and class code system was explained in Quarterly Report No. I.

3.2 Procedure

Units which showed failure or marginal results were removed from the test and submitted to electrical failure analysis.

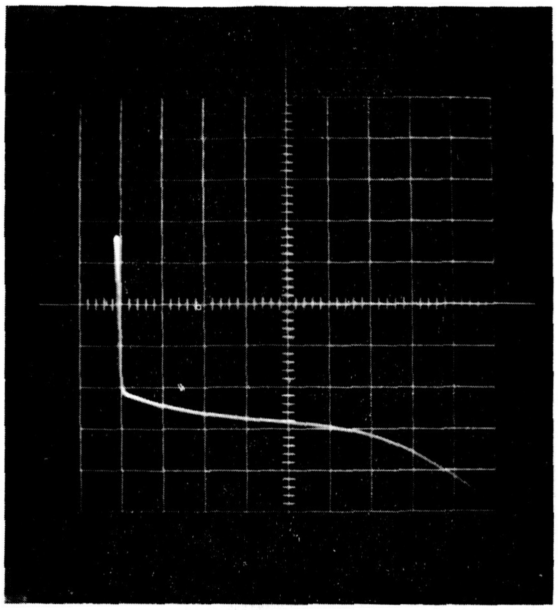
Each failure was classified by the class code which was most applicable to the particular failure.

Units then were submitted to the stresses, and mechanical, chemical, or spectrographic analysis where indicated. Photographs were made of all types of failures visible under the microscope or on the curve tracer. This report covers the specific details of the failures.

3.3 Additional Failure Class

Failure class code (h) was used to identify a failure mechanism characterized by an open collector.

3.4 Failure Conditions Observable on Curve Tracer



20 MA / Sq.

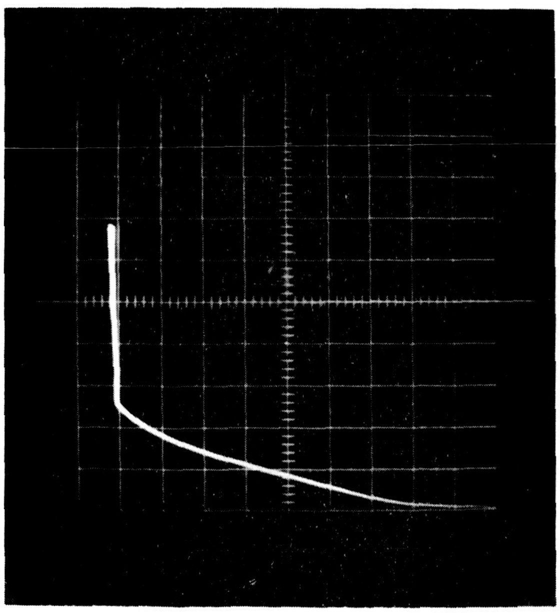
IV/Sq.

Fig. 3.4.1 - High ICBO due to surface defect.

Fig. 3.4.1 shows high ICBO as indicated on a curve tracer. This leakage was due to a surface failure. The shape of the curve at low voltage is characteristic of surface failures.

The conditions which cause surface failure of this type are reversable. The unit can be recovered by a high temperature bake with the transistor cap removed.

Failure Class a/b



.1 MA / Sq.

IV/Sq.

Fig. 3.4.2 - Leakage due to internal defect.

Fig. 3.4.2 shows a unit having high ICBO due to an internal defect. The difference between this and the previous curve is a soft exponentially increasing current as opposed to the saturating nature of the previously described surface leakage type.

This type of failure condition is not reversable and must be verified by mechanical examination.

Failure Class c

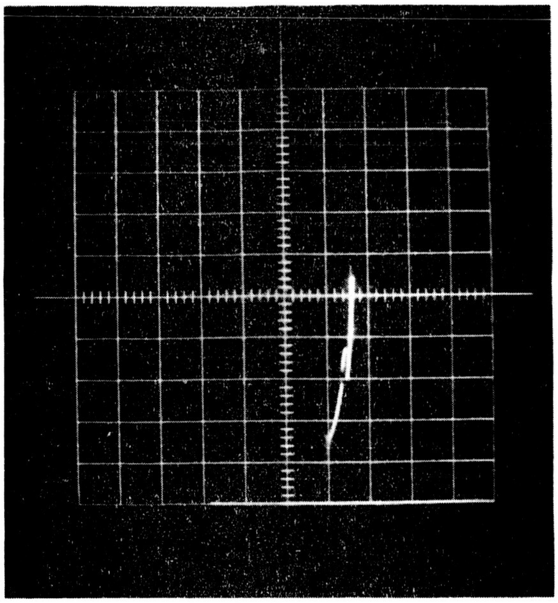
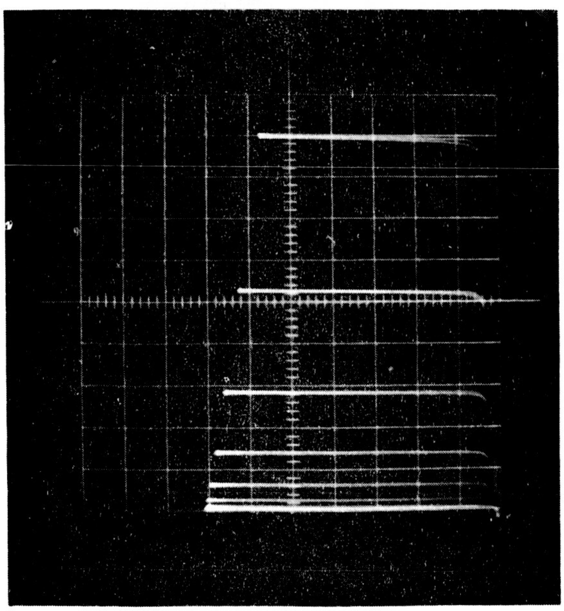


Fig. 3.4.3 shows the trace of ICEO of a cracked unit. Several stepped noisy breakdowns are sometimes seen with cracked units.

20 MA
Sq.

<u>Failure Class d</u>

20V/1 Sq.
Fig. 3.4.3 - Cracked Unit.



This picture shows the effect of badly degraded h_{FE}. This is due mostly to a surface failure type b (e - b junction). This is usually reversible by heating as the surface recovers.

105 MA
Sq.

<u>Failure Class b</u>

IV/Sq.
9 Steps .02 MA
Fig. 3.4.4 - h_{FE} Degradation

3.4.5 The previous examples show the results of the first procedure used in failure analysis. This information combined with the test data shown on the analysis sheet such as Fig. 3.7.1, front of analysis sheet showing life data and 3.7.2 reverse of analysis sheet showing observations required for complete classification of failure mode. These are included at end of 3.7.

3.5 Other Analysis Methods.

3.5.1 Visual Failure Analysis

The next procedure used in failure analysis is visual examination. This is done by removing the cap of the transistor and examination under a microscope. Many of the conditions causing failure are visible as shown in the series of pictures in 3.6.

3.5.2 Reaction to Gas

The units also were opened and subjected to N_2, O_2, air, or H_2O as a means of further identification of failure mechanism.

3.5.3 Analysis by Bake

Units were also baked at 200°C or 300°C to determine if effects were reversible.

3.5.4 Re-test of noise after recovery by baking

Units which recovered by the high temperature bake were re-tested for noise. Noise partially recovered on some units but evidence is inconclusive. This will justify a more detailed study.

3.5.5 Electrolytic Procedures

Suspected cracks and crystal damages under lead contacts were made visible by electrolytically dissolving gold wires and aluminum contacts in a high pH KCN solution. Any physical procedure to remove bonds may in itself cause damage which masks the original defect.

3.5.6 Examination by Luminescence

Examination for micro-cracks or micro-plasma was made by observing the transistor under a high power microscope while passing high reverse currents. Frequently, this procedure reveals glowing micro-cracks or micro-plasma (hot spots) which would not be visible otherwise.

3.5.7 Cap Discoloration

Observation of the interior of the cap may show discoloration which can be used as a clue to the failure type. Discoloration indicates presence of an oxidizing gas.

3.5.8 Mass-Spectrometer Analysis Gas Analysis

Nine units were submitted to gas analysis by the mass spectrometer to determine differences in the gases present in the cap. Fig. 3.5.8.1 and 3.5.8.2 show the reports returned from the spectrometer.

One process c unit submitted as a control sample proved to be a leaker, as indicated by a 0 gas volume after the spectrometer containing the unit had been pumped down.

Larger numbers of failures due to phase II and III tests will permit better correlation between failure mode and gas present in the cap.

MASS SPECTROMETER ANALYSIS

Sample No.

File No. 7

Sample Description:

Charge No. 414-5700-7003

Transistors

Submitted by: A. Poe
SPD Eng.
Bldg. 7, Elec.Park

Mole Percent

Transistor No.	O_2	H_2O	N_2/CO	Ar	CO_2	Liter-Microns
A 196 Control	0	0	98.2	0.04	1.7	24.7
B 81 Control	0	0	99.7	0.30	0	22.0
C 421 Control	Leaker - No Analysis					
A 366	0	0.09	99.7	0.02	0.2	27.9
C 76	Trace	0	98.1	0.26	1.6	42.8
C 599	0	0	97.7	0.27	2.1	42.2

Date: March 19, 1964

Signed: W E Leyshon

MATERIALS & PROCESSES LABORATORY
Building 3, Rm. 13, Ext. 3139
Electronics Park

FIGURE 3.5.8.1

MASS SPECTROMETER ANALYSIS

Sample No. ____________

File No. 7

Charge No. 414-5700-7003

Sample Description:

Transistors, NASA Contract 8-11059

Submitted by: A. Poe
SPD, Eng.

Transistor No.	Water	Nitrogen	Oxygen	Argon	Carbon Dioxide	Liter Microns
A 323	0.06%	77.7	21.2	1.04	-	16.7
B 329	0.2	99.4	-	0.2	0.2	22.7
C 83[redacted]	-	98.7	-	0.2	1.1	41.1

Date: Feb. 21, 1964

Signed:

MATERIALS & PROCESSES LABORATORY
Building 3, Rm. 13, Ext. 3139
Electronics Park

FIGURE 3.5.8.2

3.5.9 Spectrographic Analysis Results

Spectrographic analysis of the pellet was made on 2 units to determine the presence of Germanium in the pellet mount alloy. This would help to explain the failure by open collector under high temperature stresses because of the lower melting point of germanium - gold alloys.

A small amount of germanium was present in the Process B unit but not in the Process C unit. (See Figure 3.5.9.1)

3.6 Failure results as shown by photographs.

3.6.1 Some but not all failures produce results visible on a photograph made directly of the open pellet without treatment such as etching and other processes.

This section shows photographs such as can be seen without the special techniques.

Any individual failure may be due to a combination of effects; some visible on direct viewing (or photograph), others visible after special treatment and still others which are more easily understood from other types of measurement.

3.6.2 Failures - Class C

Bulk degradation failures may be characterized by high ICBO, soft BV_{CBO} curves or breakdowns at low voltages.

This failure type occurs most frequently on a reserve bias test under very high temperature conditions and may develop in use if power surges from power supplies occur.

The defect may initiate at some internal defects or micro-crack site. A localized alloy spot frequently is located under the aluminum ring area.

Severe thermal runaway may occur at the localized area.

RTD 655-26 (3-61)

GENERAL ELECTRIC

MATERIAL & PROCESSES LABORATORY

DATE ISSUED 3/18/64 VENDOR ______ LAB # 21660

CHARGE # ______ DWG, PART, HEAT OR SIZE ______ QTY. 2

PURCHASE # ______ SPEC. NO. ______ MATERIAL ______

PLEASE PERFORM THE FOLLOWING SERVICES: (1) - Sample of 3/4/64

(2) " " 3/13/64

Spectrographic analysis.

UNIT # ______ DEPT. # SPD #7 Rm. G 78 SIGNED Hans Heymdin (Foreman issuing order)

LABORATORY COMMENTS:

(1) - Mostly silicon & Aluminum - Very Small (PPM) amounts of gold & Germidinium.

(2) - Only silicon & Aluminum found.

Figure 3.5.9.1 DATE COMP 3/18/64 SIGNED [signature]

(OVER)

Reject Code C

Unit: A 257 Lot # 343201

Stress Type: Temperature Only

Failure Step: 4 at 380°C

(Theoretical 100% Failure Temperature)

Reject Code: C

Gold of B-lead alloyed into the Si cb short.

b - opened; (e - opened during test)

Figure 3.6.2.1

Unit: A 527 Lot # 343206

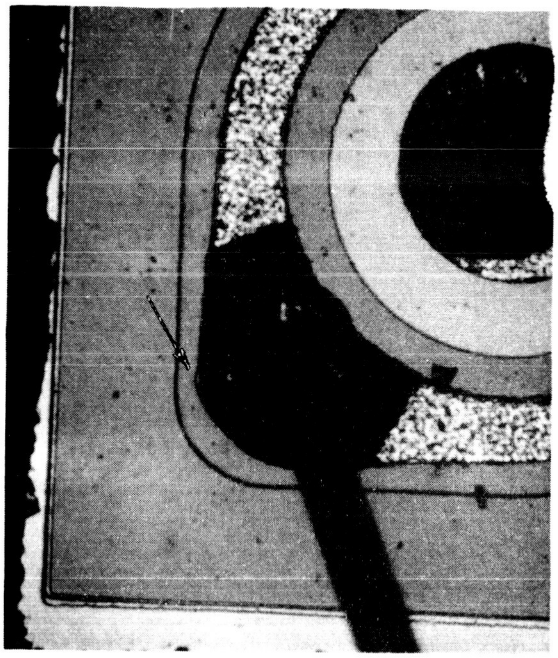
Stress Type: Power

Failure Step: 2 at 670 mw 20V

Reject Code: C

1. Gold of B-lead alloyed into Si cb short.
2. b melted open. Au diffused deeply into Al ring (up to point 2).

Figure 3.6.2.2



Unit: C441 Lot # 343201

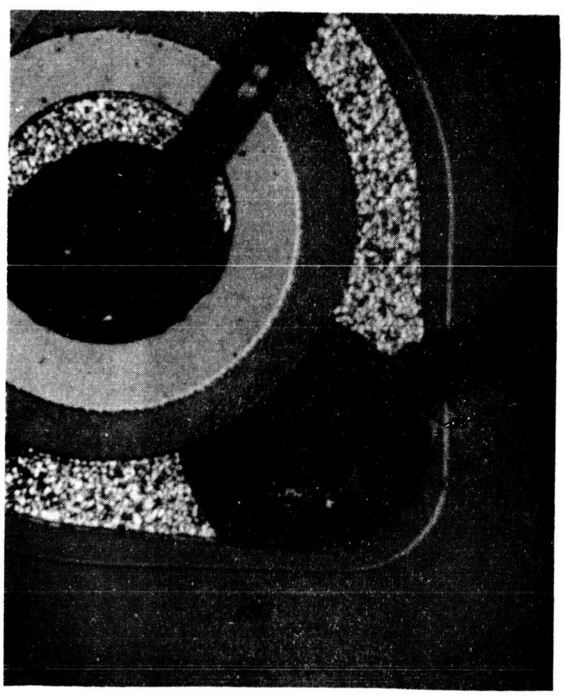
Stress Type: Temperature

Failure Step: 2 at 300° C.

Reject Code: C

Crack under base lead (visible) - confirmed by electrolytic solution of contacts.

Figure 3.6.2.3



Unit: C122 Lot # 343201

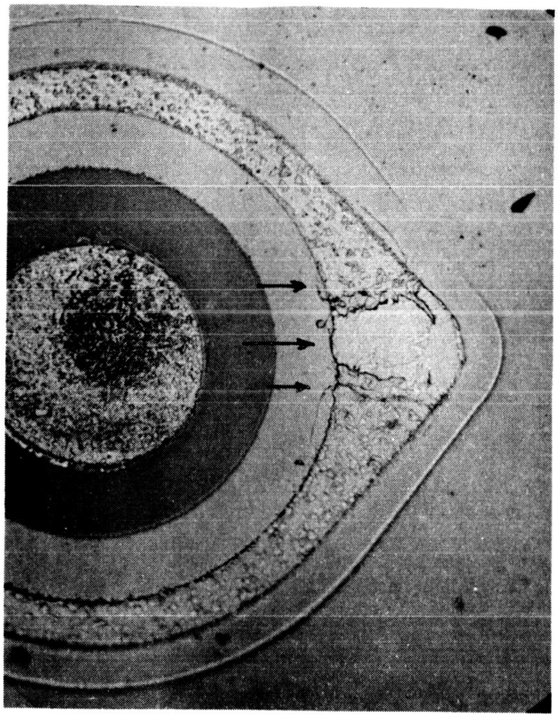
Stress Type: Temperature

Failure Step: 2 at 300° C.

Reject Code: C

Crack under base lead (visible)

Figure 3.6.2.4



Unit: C209 Lot # 202

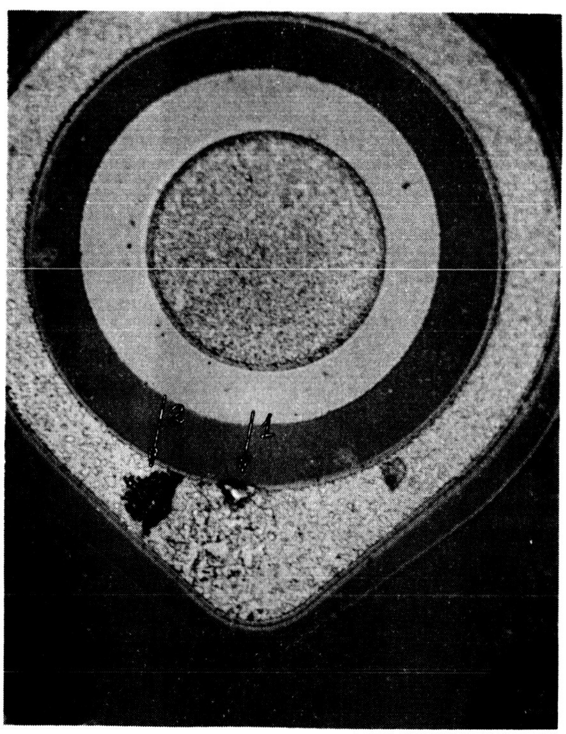
Stress Type: Temperature

Failure Step: 3 at 340°C

Reject Code: C

Cracks under the base lead bonding (visible here after dissolving electroy-tically gold wires and aluminum ring).

Figure 3.6.2.5



Unit: C180 Lot # 343201

Stress Type: Temperature

Failure Step: 3 at 340°C

Reject Code: C

1. Crack under the base lead (visible after dissolving of the gold lead).
2. Black spot is an alloy defect site in the base ring.

Figure 3.6.2.6

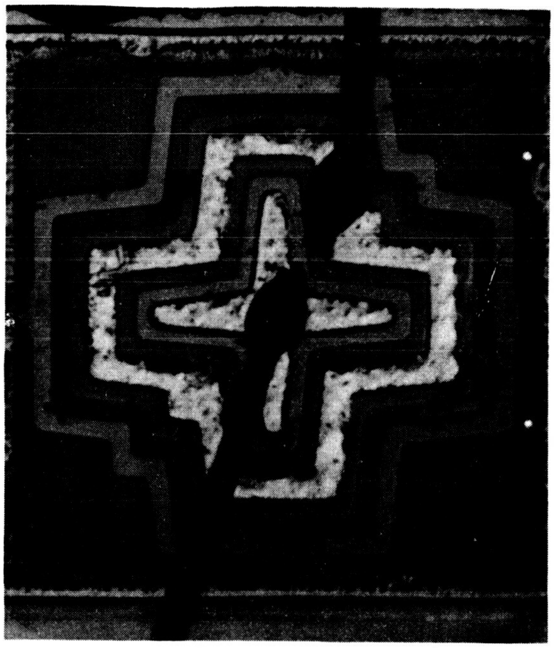


Figure 3.6.2.7

Unit: B 150 **Lot #** 343203

Stress Type: Temperature and Voltage

Failure Step: 3 (2) at 340°c and 30 V

Reject Code: C

Bulk Degradation b - c

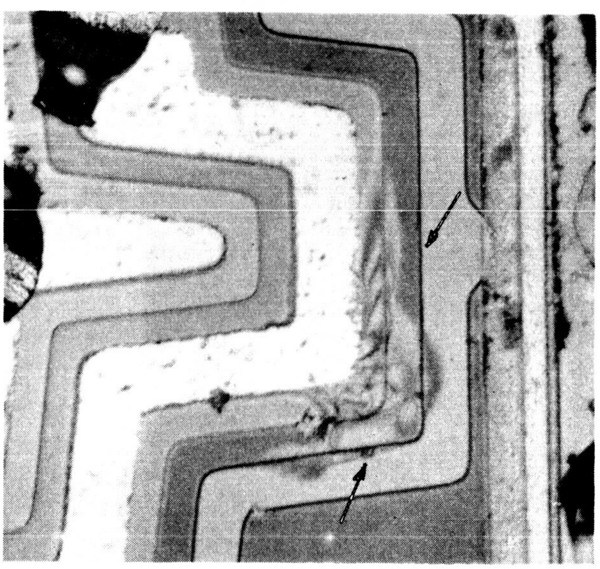


Figure 3.6.2.8

Magnification of the Failure Spot.

3.6.3 Failures Class d

Class d failures are characterized by CE shorts or low breakdown voltages limited by CE punch through, BV_{CEO} double switch backs also fall in this category. This failure type occurs most frequently on power dissipation and can be caused by voltage surges in equipment.

The failure can initiate in a defect site or microcrack in the emitter aluminum area. An "N" doped alloy spot penetrates down through the base and eventually into the collector.

Reject Code f (opens)

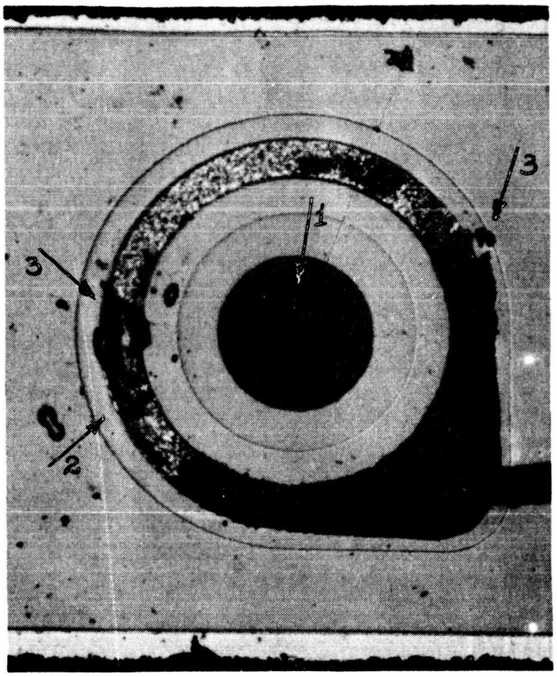


Figure 3.6.3.1

Unit: C529 Lot # 343204

Stress Type: Temperature & Voltage

Failure Step: 3 at 340°c+ 30V

Reject Code: fl

1. The emitter wire is open, due to brittle Au-Al compound ("purple plague") formation.
2. Probably cracks visible.
3. Indicates base-aluminum ring poorly processed.

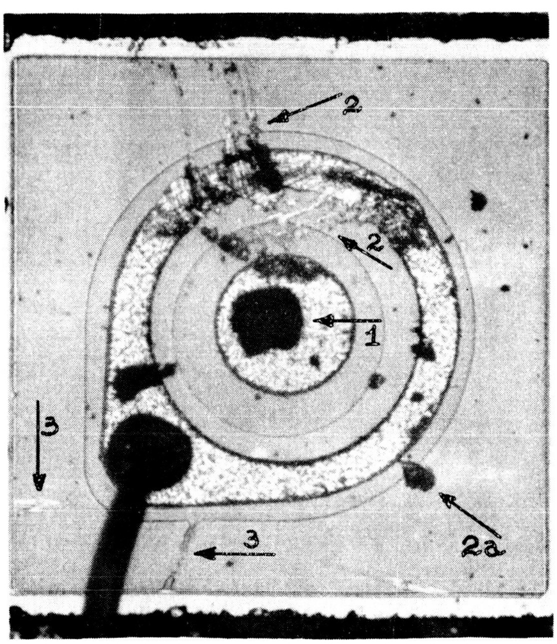


Figure 3.6.3.2

Unit: C457 Lot # 343207

Stress Type: Centrifuge

Failure Step: 4 at 150 KG

Reject Code: fl

1. Emitter wire of pellet at Al-Au interface.
2. Al base-ring badly scratched.

2a. Foreign material on pellet (not into the junction).

3. b-c junction goes into the edge (does not occur as failure at this test).
4. Oxide defect into the e-b junction.

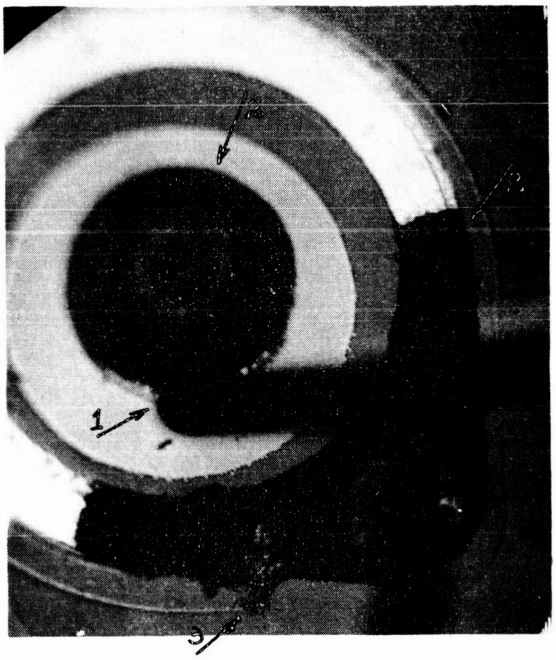


Figure 3.6.3.3

Unit: 72 Lot # 343204

Stress Type: Temperature & Voltage

Failure Step: 3 at 340°c+ 30V

Reject Type: f3/a

1. The emitter wire is broken due to Au-Al brittle compounds diffused up into the wire.
2. "Purple Death" in base.
3. Scratched Al base ring.

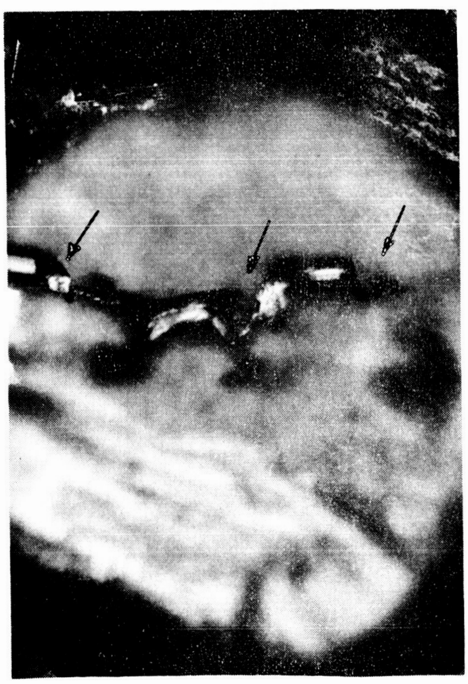


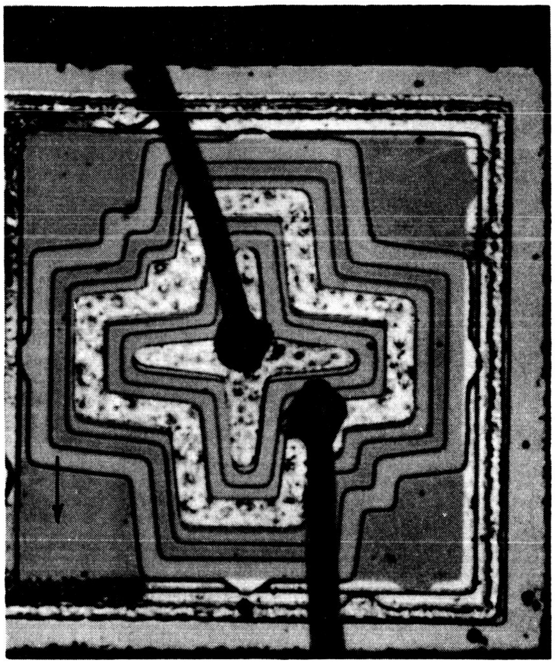
Figure 3.6.3.4

Unit: B 405 Lot # 343203

Picture of one of the weak post connections of the B-units.

Wire almost cut through due to excessive bonding pressure. Reason for most rejects of B process using Al wire: f4

Al wires are bonded to Au plated posts. Many units of type B exhibit overbonding at these points. The very thin Al wire sections resulting are very susceptible to Au diffusion at high temperatures and break off easily under relatively mild stresses.



Unit: B 383 Lot # 343202

Stress Type: Temperature

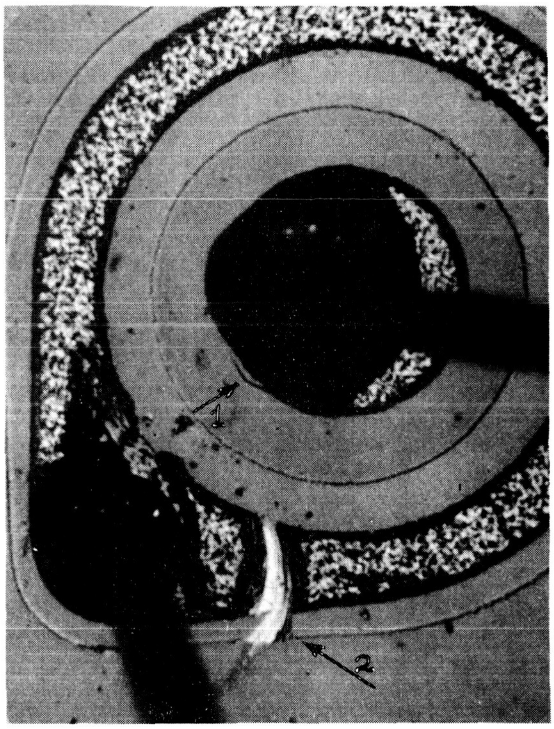
Failure Step: 2 at 300° C.

Reject Code: f4

Very weak post connection (not visible here).

The crack in this case did not cause failure because it did not extend to a junction.

Figure 3.6.3.5



Unit: C160 Lot # 343201

Stress Type: Temperature

Failure Step: 2 at 300°C.

Reject Code: d

1. Crack in emitter - collector.
2. Note aluminum base ring is scratched over the b-c junction. However, this is not responsible for failure of this device.

Figure 3.6.3.1

3.6.4 Failure Class F

Class F failures are characterized by open wire connections at different places and for different reasons. Opens may occur at the pellet Aluminum-Gold interface due to formation of brittle Au-Al compounds (f-1). Another class of opens occurs at posts due to bonding under poor conditions (f-4). Failures caused by the wire melting open during very high temperatures during thermal runaway conditions are classified (f-5).

Poorly alloyed aluminum contacts may tear open under stress - f-2 failure Severely overbonded gold nailhead or TCB bonds are easily penetrated by Aluminum from the underlying contacts, under high thermal conditions and result in broken wires - (f-3).

3.7 Representative Analysis Sheets for Failure Analysis

The work sheets used for several of the most interesting failures are included as Fig. 3.7.1 - 3.7.12. These sheets illustrate the many steps used in determining each form of failure.

Full explanation of each of these steps would be too complex and detailed to be justified as a part of this report. The total number of work sheets on hand also is too large to include as a part of the report.

All test sheets are available for analysis where circumstances indicate a need to review the data.

FIG 3.7.1

GENERAL ELECTRIC COMPANY

S.P.D. - SYRACUSE, N.Y.

FAILURE ANALYSIS REPORT FORM

CONTRACT: NASA 8-11059

PROCESS ______________ LOT 3 4 3 2 0 1 UNIT H257 NO. 7

TEST HISTORY & DATA

PARAMETER	CONDITION		INITIAL	STEP 1	STEP 2	STEP 3 340°C	STEP 4 380°C	STEP 5	NOTE SEE REVERSE
I_{CBO1}	5V	A M	.20	.30	.10	.30	-.20		
I_{CBO2}	60V	A M	.30	.10	<.10	.30	.20		
I_{EBO}	5V	A M	.3	.2	<.1	.5	.1		
I_{CEO}	5V	A M	<.1	.5	.2	.1	>9999		
B_{VCEO}	0.1 ma	A M	53.6	53.4	53.1	53.5	00.6		
$V_{CE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	187	189	192	216 coll cont. degrading	2.06V		
$V_{BE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	795	789	789	789 E contact OK	9999		
h_{FE}	V_{CE} = 5V Ic	A M	203	198	204	200	9999		
I NOISE									
100n 5 uA			380	240	250				
[illegible] 5 mA			180	16[illegible]	170				
1Kc 30 mA			1500	[illegible]	1500				
10Kc 30 mA			5200	4400	4400				
100Kc 30 mA			1700	1500	1700				

SUMMARY

1. Failure Mode: – Temp above design limit of device
2. Reject Code Type: C caused destruction of device
3. Failure Analysis Procedure: See below.
4. Failure Mechanism/s, basic cause/s and conclusion/s:

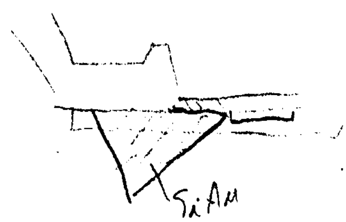
5. Recommendation/s for corrective action:

FAILURE ANALYSIS PROCEDURE

I_{ebo} → base open

I_{eceo} → .5V R = 26.6 Ω 9.5 BV_{ECO}

decap



NOTES

base open; gold in Si alloyed; short in cb; e - opened after pushing picture taken! ✓

ENGINEERING:

H. G. Zaymann / / H Pol / RG Funck

Reject Analysis Engineer - Quality Control - Reviewed By - Project Engineer

Fig 3.7.3

GENERAL ELECTRIC COMPANY

S.P.D. - SYRACUSE, N.Y.

FAILURE ANALYSIS REPORT FORM

CONTRACT: NASA 8-11059

C180

PROCESS ______________ LOT 343201 UNIT ________ NO. 26

TEST HISTORY & DATA

PARAMETER	CONDITION		INITIAL	STEP 1 (250°)	STEP 2 (300°)	STEP 3 (340°C)	~~STEP 4~~ Rdg 1 after: decap	~~STEP 5~~ Rdg 2 after: 36h 300°C	~~NOTE SEE REVERSE~~ Rdg 3 after: 48h 305°
I_{CBO1}	5V	A M	.40	<.10	.26	(2) 31.0 μa	28 μ	.25 m	.22 m
I_{CBO2}	60V	A M	1.3	1.3	1.3	38.0 μa	29 μ	1.7 m	2.5 m
I_{EBO}	5V	A M	1.5	.96	1.5	930.0	700 n	150 n	5 m (2.V) ? 11 m (1V)
I_{CEO}	5V	A M	<.10	.40	.20	31.0 μa	29 μ	.2 m	.22 m
BV_{CEO}	0.1 ma	A M	103.4	102.9	125.1 128.2	[illegible] 63.6			
$V_{CE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	120.	[illegible]	119.	[illegible] 145.			
$V_{BE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	785	782	779	791			
h_{FE}	V_{CE} = 5V Ic	A M	319.9	205.	355.	[illegible] 508.0			
I NOISE									
100n 5 uA			310		[illegible]				
1Kc 5 mA			180	[illegible]	200				
1Kc 30 mA			780	[illegible]	[illegible]				
10Kc 30 mA			3200	2600	5000				
100Kc 30 mA			1700	1650	2200				

FIG 3.7.4

C180

42

-2-

C/b

SUMMARY

1. Failure Mode: Crack in unit degrades surface wise - responsible for failure
2. Reject Code Type: C (b)
3. Failure Analysis Procedure: See below.
4. Failure Mechanism/s, basic cause/s and conclusion/s: h_{FE} never recovers - no visible reason - b

5. Recommendation/s for corrective action:

FAILURE ANALYSIS PROCEDURE

30μA C7V

CEO = CBO

EBO

h_{FE} severely degraded

I_{CO} inversion

30μA → pushing 75V CEO = CBO (nothing visable)

Heat: 300° (26h)

I_{ebo} — $BV_{cbo} = I_{ceo}$

I_{ceo} 9.6V 122V — $h_{FE} =$ 20m / 420m (degr.!)

→ permanent failure

Heat 300° (48 h) Rdg → 3

I_{EBO} 9.6V

I_{CEO} 160V

BV_{CBO} 175 →

NOTES

Inversion layer - ~~recovered~~

high I_{EBO} → get worse with temps. → permanent failure

after desolving of the Au & Al → crack under land base

Picture taken ✓

ENGINEERING:

Dr-G Heymann / A Poe / Robert Quick

Reject Analysis Engineer - Quality Control - Reviewed By - Project Engineer

Fig. 3.7.5

GENERAL ELECTRIC COMPANY

S.P.D. - SYRACUSE, N.Y.

FAILURE ANALYSIS REPORT FORM

CONTRACT: NASA 8-11059 B150

PROCESS ______ LOT 843203 UNIT ______ NO. 17

TEST HISTORY & DATA

PARAMETER	CONDITION		INITIAL	STEP 1	STEP 2 (300-30V)	STEP 3 (410°-20V)	STEP 4	STEP ~~5~~ (Rdg 1 after: decap)	NOTE SEE REVERSE (Rdg 2 after: 26h 300°C)
I_{CBO1}	5V	A	.10	.20	23.7	C2 6.9 ma			
		M			380.0	6.3 na		360 n	480 n
I_{CBO2}	60V	A	4.7	2.5	@	986.0			
		M			31.0 ua	940.0		920 n	1.9 ma
I_{EBO}	5V	A	5.7	6.0	5.3	5.2			
		M			5.9	—		9.8 n	5 na
I_{CEO}	5V	A	.20	.20	148.7	22.0		420 n	19 ua ?
		M			2.9 ua	18.5			
BV_{CEO}	0.1 ma	A	62.6	63.0	20.7	56.0			
		M			17.5	55.7			
$V_{CE(sat)}$	Ib = 5 ma	A	109.	105.	104.	C-2			
	Ic = 50 ma	M				NR			
$V_{BE(sat)}$	Ib = 5 ma	A	800.	798.	796.	730.			
	Ic = 50 ma	M				735.			
h_{FE}	V_{CE} = 5V	A	248.	252.	275.	217.8			
	Ic	M				252.0			
I NOISE									
100n 5 uA			520	500	0000			.027	
1Kc 5 mA			190	200	0000			.016	
1Kc 30 mA			1300	1300	1800			.92	.86 *
10Kc 30 mA			5200	4200	2200			.95	
100Kc 30 mA			1900	1800	4800			.14	

* after .86 → ↑↑ in 1KC and 10KC → ↓ NR

FIG 3.7.6

B150

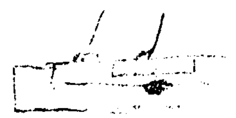
C

SUMMARY

Appears to be a defect area in E

1. Failure Mode:
2. Reject Code Type: C
3. Failure Analysis Procedure: See below.
4. Failure Mechanism/s, basic cause/s and conclusion/s:

5. Recommendation/s for corrective action:



FAILURE ANALYSIS PROCEDURE

Intermittent short
Read high leakage, then snapped / but $\frac{600\,mv}{.5\,ma}$ CBO/CEO

6.9V

I_{eb} 6.9 BV cbo 98V

I_{ceo} 40V 55V h_{FE} $\frac{100\,\mu a}{2.2} = 50$ $\frac{20\,m}{.23\,m}$

Decap [coated cap] Rdg → 1 mobil with H_2O

heat 300° (26h)
s. if I_{cb} ↓ Rdgs → 2

I_{eb} 7V 60V BVcbo 100V
I_{ceo} 35 V

Part very weak connected

NOTES

permanent damaged inside (no [illegible])

→ eb shorted $R = \frac{1V}{1mA} = 1K\Omega$ during test.

ENGINEERING:

[signature] / / A Pol / Robert [signature]

Reject Analysis Engineer - Quality Control - Reviewed By - Project Engineer

Fig 3.77

GENERAL ELECTRIC COMPANY

S.P.D. - SYRACUSE, N.Y.

FAILURE ANALYSIS REPORT FORM

CONTRACT: NASA 8-11059

PROCESS ______________ LOT 343204 UNIT A135 NO. 3

TEST HISTORY & DATA

PARAMETER	CONDITION		INITIAL	STEP 1 (250°C)	STEP 2 (300°C -30V)	STEP 3	STEP 4	~~STEP 5~~ Rdg 1 after: 50h 200°C	NOTE SEE REVERSE
I_{CBO1}	5V	A	.46	1.0	16.6			.9ma	✓
		M			15.6				
I_{CBO2}	60V	A	1.0	1.9	37.5			1.7ma	✓
		M		2.0	33.0				
I_{EBO}	5V	A	.56	.30	Code 2			.36ma	✓
		M			170ua				
I_{CEO}	5V	A	.50	1.7	17.4			1.4ma	✓
		M			15.0				
B_{VCEO}	0.1 ma	A	51.5	52.1	119.2				
		M			113.0				
$V_{CE(sat)}$	Ib = 5 ma	A	195	197	209				
	Ic = 50 ma	M							
$V_{BE(sat)}$	Ib = 5 ma	A	790	788	787				
	Ic = 50 ma	M							
h_{FE}	V_{CE} = 5V	A	261.8	258.0	468.9				
	Ic	M			495.6				
I NOISE									
100n 5 uA	10^{-14}		240	276	400			800÷1200	
1Kc 5 mA	10^{-14}		170	170	140			400	
1Kc 30 mA	10^{-13}		1300	1500	1800			1150	
10Kc 30 mA	10^{-14}		4800	4100	5700			3000	
100Kc 30 mA	10^{-14}		2100	1700	2800			1400	

A135

b/a

SUMMARY

1. Failure Mode: h_{FE} (EB surface) degraded under heat
2. Reject Code Type: b/
3. Failure Analysis Procedure: See below.
4. Failure Mechanism/s, basic cause/s and conclusion/s:

5. Recommendation/s for corrective action:

FAILURE ANALYSIS PROCEDURE

I_{ebo} 250 μa 9V

BV_{cbo} 115V

I_{ceo} 1.5V 115V ?

h_{FE} $\frac{100\mu}{65}$ degr.

Decap (hole)

No change N; O; Vac especially Iebo $h_{FE} = \frac{100\mu}{47\mu}$ degr. $\frac{20 ma}{.36}$ degr.

$H_2O \rightarrow$ I_{ebo} = 200 μa stabil / BV_{cbo} = 80 μa mobil

I_{ebo} 9.2V

BV_{cbo} = 105V

h_{FE} no ready 100μ $\frac{20 ma}{.34}$

I_{ceo} 1.5V 68V

$h_{FE} = \frac{100\mu}{4.6\mu}$ $\frac{20 m}{.25 m}$ recovered

Rdeg. →

heat (200°) (50 h...

NOTES

recovered / Picture taken ✓

ENGINEERING:

Reject Analysis Engineer	Quality Control	Reviewed By	Project Engineer
J. G. Jagman		A Pol	R G Quick

Fig 3.7.9

GENERAL ELECTRIC COMPANY

S.P.D - SYRACUSE, N.Y.

FAILURE ANALYSIS REPORT FORM

CONTRACT: NASA 8-11059

PROCESS ______________ LOT 343204 UNIT 20 NO. B-516

TEST HISTORY & DATA

300°C-30 340°-30V Rdg 1 after: 26h 300°C

PARAMETER	CONDITION		INITIAL	STEP 1	STEP 2	STEP 3	STEP 4	~~STEP 5~~	NOTE SEE REVERSE
I_{CBO1}	5V	A M	.150	.20	.20	(2) 11.9 μa 13. μa		.11 ma	recovered
I_{CBO2}	60V	A M	1.0	.90	.70	(2) 82.8 μa 64. μa		.1 ma	"
I_{EBO}	5V	A M	.8	.1	.4	(2) 40.8 μa 40 μa		.15 ma	"
I_{CEO}	5V	A M	.1	.1	<.1	(2) 10.1 μa 12. μa		.21	"
B_{VCEO}	0.1 ma	A M	73.8	73.4	72.6	(2) 62.8			
$V_{CE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	98.	98.	95	149.1 —			
$V_{BE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	798	798	797	0 —			
h_{FE}	V_{CE} = 5V Ic	A M	211.4	206.	202.	438 616			
I NOISE									
100n 5 uA			300	280	440		.028		
1Kc 5 mA			180	170	360		.016		
1Kc 30 mA	13		1900	2100	1800		1.3		
10Kc 30 mA			6200	6400	5900		.3		
100Kc 30 mA			1900	1800	2300		.1		

FIG 3.7.10

B 516

48

(a - b)

SUMMARY

1. Failure Mode: a/b
2. Reject Code Type:
3. Failure Analysis Procedure: See below.
4. Failure Mechanism/s, basic cause/s and conclusion/s:

5. Recommendation/s for corrective action:

FAILURE ANALYSIS PROCEDURE

I_{ebo} 25 μa 7 V

BV_{cbo} 20 μa 65

I_{ceo} 20 μa 65 V

h_{FE} degr $\frac{100\ \mu a}{82\ \mu a}$ $\frac{20\ ma}{.5\ ma}$

Heat 300° (26 hours) Rdg → 1

I_{ebo} = 7.7

BV_{cbo} Noise 140 V

I_{ceo} = noise 78V 60V

h_{FE} : $\frac{100\ \mu a}{.9\ \mu a}$ $\frac{20\ ma}{86\ \mu a}$

NOTES

measured! CB / hFE! surface failure (a; b) . coulbered cap

Nothing visible - No defect seen!
Surface failure in spite of guard ring.

ENGINEERING:

H. G. Jergmann / A. Pal / Robert G. Finck

Reject Analysis Engineer - Quality Control - Reviewed By - Project Engineer

Fig 3.7.11

GENERAL ELECTRIC COMPANY

S.P.D. - SYRACUSE, N.Y.

FAILURE ANALYSIS REPORT FORM

CONTRACT: NASA 8-11059

PROCESS ______________ LOT (Power) [illegible] UNIT C392 NO. 27

TEST HISTORY & DATA

PARAMETER	CONDITION		INITIAL	STEP 1	STEP 2	STEP 3	STEP 4	~~STEP 5~~ Rdg 1 after: 50h 200°C	NOTE SEE REVERSE Rdg 2 after: 26h 200°C
I_{CBO1}	5V	A M	.1	.1	.50 .20	(2) 22.6 μa 23.0 μa		340 ma	2.5 m / 2.4 [illegible]
I_{CBO2}	60V	A M	.5	.5	.5	(2) 56.6 μa 57.0 μa		350 ma	3 ma / 2.6 [illegible]
I_{EBO}	5V	A M	6.3	4.7	7.4	(2) 160.0 μa		130 μa	640 μa / 13[illegible]
I_{CEO}	5V	A M	.3	.2	1.3 .30	(2) 24.2 μa 24.0 μa		320 ma	2.8 ma / 1[illegible]
B_{VCEO}	0.1 ma	A M	78.2	75.9	76.2	105.8 105.2			
$V_{CE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	103	100	99	107			
$V_{BE(sat)}$	Ib = 5 ma Ic = 50 ma	A M	776	774	769	778			
h_{FE}	V_{CE} = 5V Ic	A M	251	234	225.9	524. 521			
I NOISE									
100n 5 uA			270	790	240			NR	.04
1Kc 5 mA			170	190	170			.37	.015
1Kc 30 mA			1200	1400	500			.8	2.2
10Kc 30 mA			4200	4400	3900			.27	.7
100Kc 30 mA			1700	1800	2500			.11	.22

FIG 3.7.12 C 392 50

P V G/e

SUMMARY

1. Failure Mode: Crack explains CBO degradation showing up as a surface effect at the exposed crack
2. Reject Code Type: c
3. Failure Analysis Procedure: See below.
4. Failure Mechanism/s, basic cause/s and conclusion/s: hFE-degradation is probably due to bulk changes under high power condition – (gold diffused into EB junction)

5. Recommendation/s for corrective action:

FAILURE ANALYSIS PROCEDURE

Iebo .5μa 9.5V BVcbo 50μa 50V 150V

Iceo .1ma 110V hFE $\frac{100}{165}$ <1 $\frac{20ma}{.52}$ degr.

decap hole

GAS EFFECTS Vcc. hFE worse slightly

CBO-50V-30μa BV=160

no change H2O in ebo; but [illegible] in ceo; cbo

heat (200°) (50h) – (in air)

.375ma 9.5V BVcb 3μa 15μa 140V ← improved

4μa 135V hFE $\frac{100}{100}$ ~1 $\frac{20ma}{.485}$ ← improved very slightly

135V Rdgs → 1

NOTES

70V

300°c (26 hours) In AIR recovered: Vcbo

Iebo .4ma 9.5V BVcbo 135

purple death in E- [illegible] covered

Iceo 135 hFE = $\frac{20ma}{.425}$

No visible junction damage

heat 300°c (26 h) Rdgs → 3

ENGINEERING: at bases checked! picture taken ✓ Rdg → 2

Reject Analysis Engineer - Quality Control - Reviewed By - Project Engineer

3.8 Summary of Results of Failure Analysis

3.8.1 Tabulated Results Per Failure Class

(See page 14 - 23, First Quarterly Report for definition of failure classes.)

FAILURE CLASS	PROCESS A	PROCESS B	PROCESS C	TOTAL
a. C-B Surface Degradation	7	0	4 (See Below)	10
b. E-B Surface Degradation	1	3	0	4
c. C-B Bulk Degradation	2	2	11	15
d. C-E Bulk Degradation	0	0	3	3
e. E-B Bulk Degradation	1	0	0	1
f_1 Open (Intermetallic)	0	0	4	8
f_3 Broken Wire	0	0	3	3
f_4 Open at Post	0	4	0	4
h Open Collector	0	5	2	7
Indeterminable	1	0	0	1
TOTAL -----	12	14	29	55

In the table failures were identified only by the dominant failure though 2 or more types of degradation of failure did exist in the same device. This gives an unbalanced impression of Process C, particularly where failure type (a) was present in a substantial number of failures. The 4 units indicated as surface failures did not show effects of other failure modes in amount sufficient to classify by the other mode.

3.8.2 Dominant Failure Mode for the Different Processes

3.8.2.1 Process A

Surface failure (a) is the most prominent failure mechanism.

The second failure mechanism (c) collector base bulk degradation is due to the gold of the base lead migrating and alloying into the pellet so as to short collector to base under the extreme thermal conditions under which the units were subjected.

The validity of use of the high temperature failures as representative of over reliability is questionable and will be carefully reviewed throughout the project.

3.8.2.2 Process B

Failure Class (f_4) is due to weak lead bonds in bonding the lead to post. The use of aluminum wires increase the problems in this area but decreases the other problems of intermetallic formation (see para. 3.6.4.4).

Failure Class H occurs when the pellet seperates from the header. The relatively high rate of failure under accelerated thermal stresses may be due to the use of a lower melting preform for collector bonding containing Germanium.

The validity of the use of an acceleration factor as index of reliability based upon this type of failure is questionable requiring careful review throughout the project.

3.8.2.3 Process C

Failure type (c) collector-base bulk degradation was the most prominent form of failure and mostly identifiable by the presence of micro-cracks under or near the connections. This is probably due to excessive lead bonding pressure. Temperatures above normal operating range may be necessary to develop the cracks.

All failures in type (c) showed some degree of type (b) E-B surface degradation (h_{fe} degradation). These units are most sensitive to gain degradation under conditions of the test.

Failure type (f_1) open lead bonds due to intermetallic formation also was present in Process c.

4.0 Noise Experiment

4.1 Purpose of the Experiment

4.1.1 The noise experiment is an evaluation of the hypothesis that a noise test can be used as an indicator of reliability or as a means of screening transistors to improve the reliability.

The experiment was planned to draw a clear distinction between the noise which occurs after a transistor has developed some form of degradation and the noise that may be detectable in a transistor and related to a failure mechanism which is not detectable by other more conventional tests.

The experiment completed in Phase I was designed to provide a sound basis for planning the experiment of Phase II & III.

4.1.2 Factors which affect the complexity of the experiment.

a. Noise which is occuring in a transistor is a measurable value which can, if sufficiently high, be a cause for rejection of the transistors as a failure.

4.1.2 (Cont.)

b. Noise also may be correlated directly to high or low values of other parameters. These parameters may be degraded and an indication of a failure of the device (high I_{CBO}, I_{EBO}, Low h_{fe}, etc.).

c. The evidence of failure of a device such as open, shorted, etc. can cause a decrease in noise for obvious reasons giving the opposite cause and effect relationship.

d. Noise which correlates directly to some other measurable parameter such as 2 and 3 is of little value as a predictor of reliability. Normally, noise tests will be more difficult than other tests and a poor substitute for the other tests.

e. Noise can be due to parameters which have no relation to reliability as well as due to parameters which are related to reliability.

f. The noise due to parameters unrelated to reliability can be of sufficient magnitude to conceal the noise which is due to factors which are related to reliability.

g. Under the conditions of (f) above, it is possible that screening units to a noise limit may eliminate more reliable units than unreliable units and result in a decrease in reliability.

4.2 Summary of Results to date

4.2.1 A noise test at high frequency (100 KC) shows little or no relation to reliability (Section 4.6).

4.2.2 Low frequency noise (100 cycle or 1,000 cycle) can be more productive in improving reliability but is effective against mechanisms which may not be present in transistors produced by all processes (Section 4.7).

4.2.3 Measurement of noise at low current increases the difficulty of measurement as noise meters are less sensitive, have a higher background noise and readings have a greater percentage tolerance than at higher currents (Section 4.5).

4.2.4 Measurement of noise to any predetermined level may reject more good units than bad units and cause a decrease in reliability (Section 4.6.7).

4.2.5 The tests to date indicate that a more detailed experiment using larger quantities is well justified.

4.3 Brief Introduction to Noise Theory

4.3.1 The experimental procedure is complex due to the complexity of the noise relations within a transistor.

A brief review of noise theory, an equivalent circuit and review of the noise measurement are given to provide a basis of explaining the procedures used (reference (1), Van der Ziel) provides a more detailed exploration of noise in semiconductors.

Noise is inherent in all electrical circuits and is due to the atomic nature of matter. The noise generated in any conductor or resistor consists of more or less amounts of spontaneous fluctuation in voltage or current.

Noise in semiconductors is due to several different mechanisms. Some of the noise sources are not related to effects which can have a relation to degradation or failure. Other noise sources possibly can be related to failure.

It is the purpose of this experiment to isolate the noise from different sources, identify those which may be related to degradation, determine roughly the amount of improvement possible, find some correlation between noise frequency and failure and lastly identify the failure mechanisms with the noise.

Phase I of this experiment covered in this report is intended mainly to determine if the experiment of Phase II and Phase III will be as effective as possible.

4.3.2 Types of Noise Present in a Transistor

There are three different broad classifications of noise in a transistor: flicker noise, shot noise and thermal noise. These three different noise types differ in their frequency range. Flicker noise (also called I/F noise) is highest at low frequencies and decreases with frequency.

Fig. 4.3.2 shows the approximate relation as generally understood.

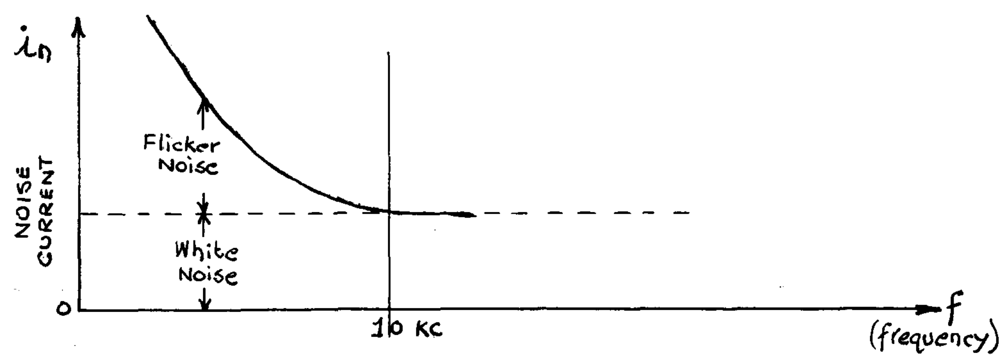


Fig. 4.3.2 Noise Spectrum

4.3.3 Thermal Noise

This type of noise is generated in an ohmic resistance and does not require external excitation. Thermal noise is due to the thermal agitation of the carriers in the material. This motion of changes is completely random and therefore the noise spectrum is completely uniform throughout the frequency range until attenuation due to capacity causes a fall off in gain of the transistor.

Thermal noise increases with temperature and band width. Since a transistor has resistance, it has thermal noise. Thermal noise can be represented by an equivalent circuit consisting of a voltage generator in series with a noiseless resistor.

Fig. 4.3.3.1

4.3.4 Shot Noise

This type of noise is also due to the discrete particle nature of charges. Current which flows through a transistor is not completely uniform due to the random diffusion of minority carriers and to the random recombination and generation of charges.

This process is also completely random and has a uniform noise spectrum similar to the thermal noise (white noise).

Shot noise is proportional to the number of carriers; i.e. to the current flow, and to the temperature and band width.

The equivalent circuit for shot noise current can be represented by a constant current generator parallel to a noiseless resistance.

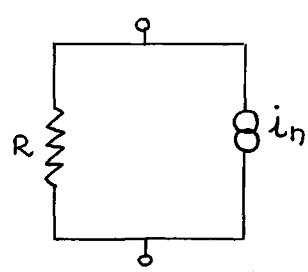


Fig. 4.3.4.1 Shot Noise Equivalent Circuit

4.3.5 Flicker Noise

This type of noise exists in addition to shot noise and thermal noise. Flicker noise occurs mostly in the low frequency region. Flicker noise has the $1/F$ frequency relationship.

Flicker noise can be divided into two causes. One would be surface leakage and the other internal leakage.

In general as reported in literature, the flicker noise is not clearly understood but some thinking is that the flicker noise is due to the traping of carriers due to charges on surfaces. Flicker noise has been reported due to the conditions at the contacts also.

Flicker noise distribution is mostly in the region up to 10,000 cycles. Above 10,000 cycles the flicker noise is masked by shot and thermal noise.

4.3.6 Equivalent Noise Circuit of a Transistor

The various noise generators are incorporated into an equivalent noise circuit. This shows one arrangement of the noise in a transistor.

All the noise sources in one element (base, emitter, or collector) are represented by a single noise voltage generator in each transistor leg.

In addition, a noiseless resistance r_e or r_c represents the ohmic resistance of the emitter and collector junctions respectively. Yb represents the ohmic resistance between the base contact and the junction.

The current generator αi_e represents the transfer of current from the emitter junction to the collector junction across the base region.

This simplified circuit shows the distribution of the different noise sources in the transistors.

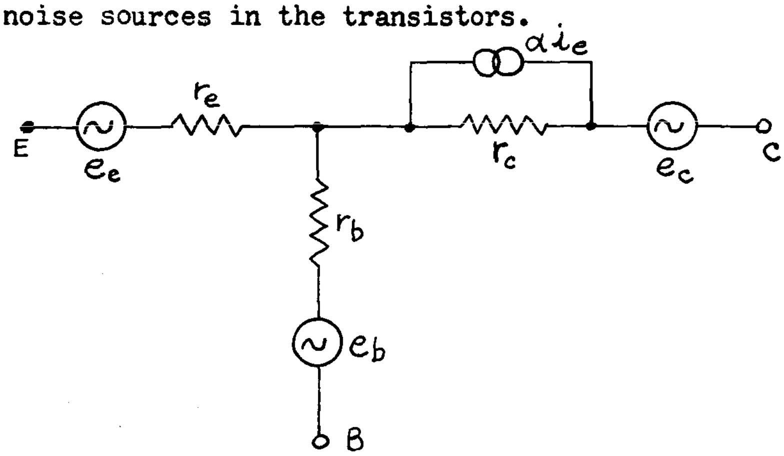


Fig. 4.3.6.1 Noise Equivalent Circuit

4.4 Noise Measurement

4.4.1 Test Conditions

Early in the investigations, the cost of noise measurement vs the potential information, was reviewed and it was expected that measurement of noise current over several points would produce more information

4.4.1 Cont.

than making the same number of measurements of noise current and noise voltage.

Noise measurements were made by two different "Quan-Tech Noise Analyzers". One was a modified Mod. 310 and the other a Mod. 310B.

The ranges of the two instruments are shown below:

	MOD. 310	MOD. 310B
Test Frequencies	1,000 ~, 200 ~, Band Width	100 ~, 20 ~, Band Width
	10,000 ~, 2,000 ~ " "	1,000 ~, 200 ~ " "
	100,000 ~, 20 KC " "	10,000 ~, 200 ~ " "
Min. Ic	100 μA	5 μA
Max. Ic	30 mA	1 mA

Initial readings were made at the following frequencies, voltages, and currents.

Ic = 5 μA - Noise current at 100, 1000 and 10,000 cycles.

Ic = 30 mA - Noise current at 1,000, 10 KC and 100 KC.

4.4.2 Test Circuit

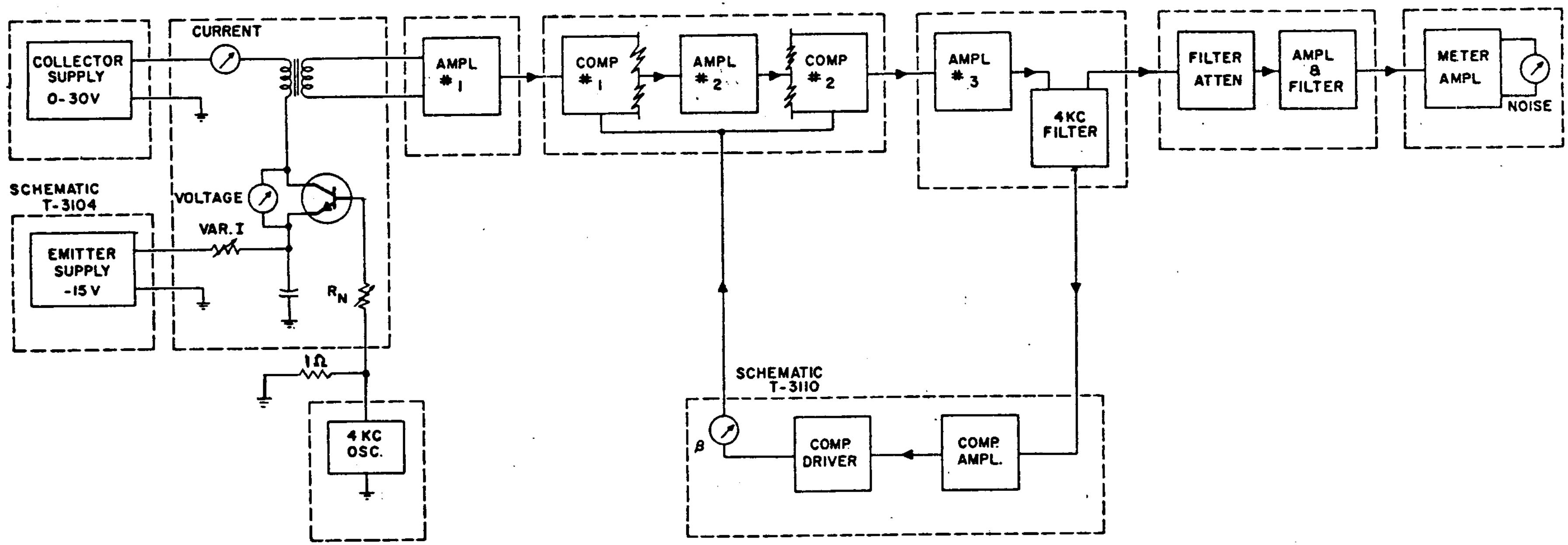
Fig. 4.4.2.1 shows a simplified circuit diagram of the noise analyzer.

The transistor under test is powered in a conventional manner so that Ic and V_{CE} are adjustable over the stated range.

The collector contains a transformer connected to the output amplifier.

Variations in gain of the transistor under test are compensated for by a variable gain amplifier which follows this transformer. To control this gain for a uniform gain at the output, a 4 kc oscillator provides a constant signal across a 1 ohm resistor in the base circuit.

This signal is amplified by the transistor under test and the variable gain amplifier. The 4 kc is filtered out and used to control the gain.



QUAN. TECH. TRANSISTOR NOISE ANALYZER
MODEL 310

DETAILED BLOCK DIAGRAM

Fig. 4.4.2.2

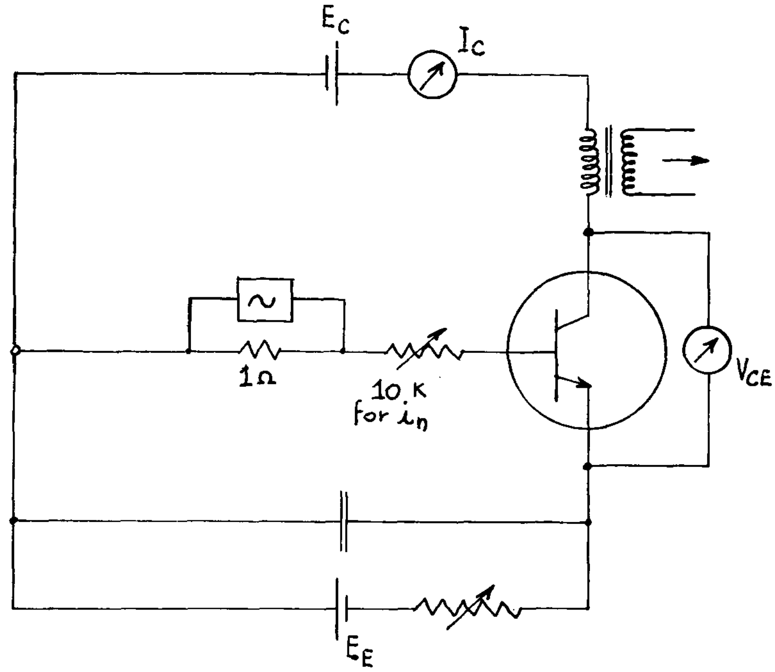


Fig. 4.4.2.2 shows the complete block diagram of the transistor noise analyzer. Both noise analyzers use the same principal and differ only in power supply and frequency ranges covered.

4.5 Noise Measurement Coverage

Informal reports by other investigators both at GE and outside indicate that there are good reasons to believe that a relation between noise and reliability exists but no reports were found where the relation was successfully proven as a production technique.

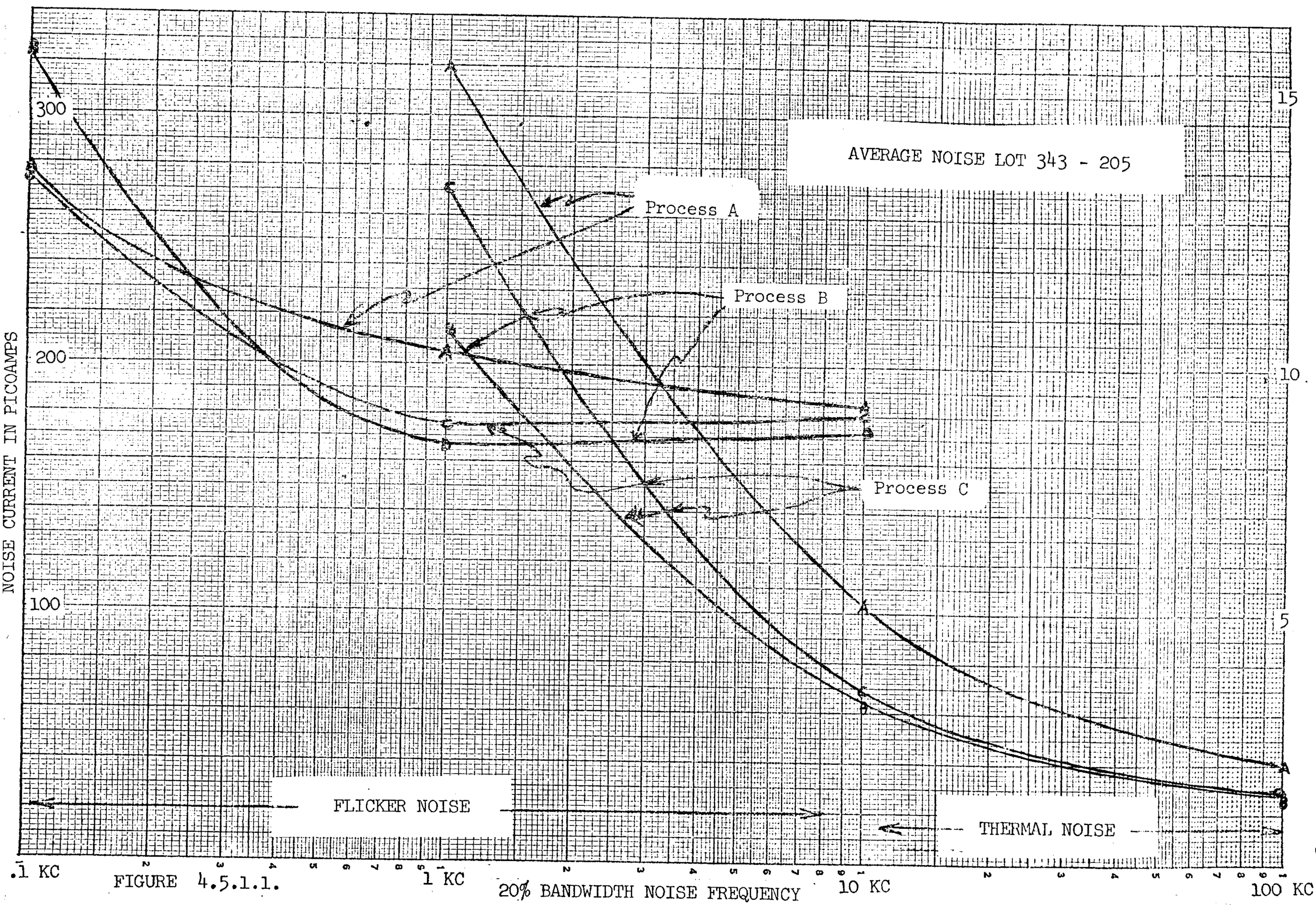
This section covers some of the practical considerations which determine the methods necessary.

4.5.1 Noise vs Frequency and Current

Fig. 4.5.1.1 shows the average noise for each process at the six measurement points taken.

The relation between noise at one frequency and another varies for the three processes. Higher frequency tests show less information due to lower values where instrument noise level and readability become serious problems.

Fig. 4.5.1.2 shows a computor distribution run out of the noise at two different levels and times. The first distribution shows the effect of the poor readability at low levels where the noise which could be associated with a failure mechanism (if such exists) would be concealed by the natural noise due to thermal and shott effects.



AVERAGE NOISE LOT 343 - 205
Process A
Process B
Process C
NOISE CURRENT IN PICOAMPS
300
200
100
15
10
5
FLICKER NOISE
THERMAL NOISE
.1 KC
1 KC
10 KC
100 KC
20% BANDWIDTH NOISE FREQUENCY

FIGURE 4.5.1.1.

```
SOURCE CD.17          PRODUCT
LOT NUMBR 343207      STRESS C
DOWNTIME  00 HRS.     TEST DAT

UPTO 0169
UPTO 0171 111111
UPTO 0173
UPTO 0175
UPTO 0177
UPTO 0179
UPTO 0181 1111111111111
UPTO 0183
UPTO 0185
UPTO 0187
UPTO 0189
UPTO 0191 1111111111
UPTO 0193
UPTO 0195
UPTO 0197
UPTO 0199
UPTO 0201
UPTO 0203
UPTO 0205
UPTO 0207
UPTO 0209
UPTO 0211 1
```

```
SOURCE CD.17              PRODUCT        112
LOT NUMBR 343202          STRESS CD.5
DOWNTIME  1000 HRS.       TEST DATE 516

UPTO 0429
UPTO 0471 1
UPTO 0513
UPTO 0555
UPTO 0597
UPTO 0639 111
UPTO 0681 1
UPTO 0723 1
UPTO 0765
UPTO 0807 11
UPTO 0849
UPTO 0891
UPTO 0933 11
UPTO 0975
UPTO 1017 11
UPTO 1059
UPTO 1101 11
UPTO 1143
UPTO 1185
UPTO 1227
UPTO 1269
UPTO 1311
UPTO 1353 11
UPTO 1395
UPTO 1437
UPTO 1479 11
UPTO 1521 1
UPTO 1563
UPTO 1605 11
UPTO 1647 11
UPTO 1689
UPTO 1731 1
UPTO 1773
UPTO 1815 11
UPTO 1857
UPTO 1899
UPTO 1941
UPTO 2025 1
UPTO 2067
UPTO 2109 1
```

FIG. 4.5.1.2 EFFECT OF INSTRUMENT READABILITY

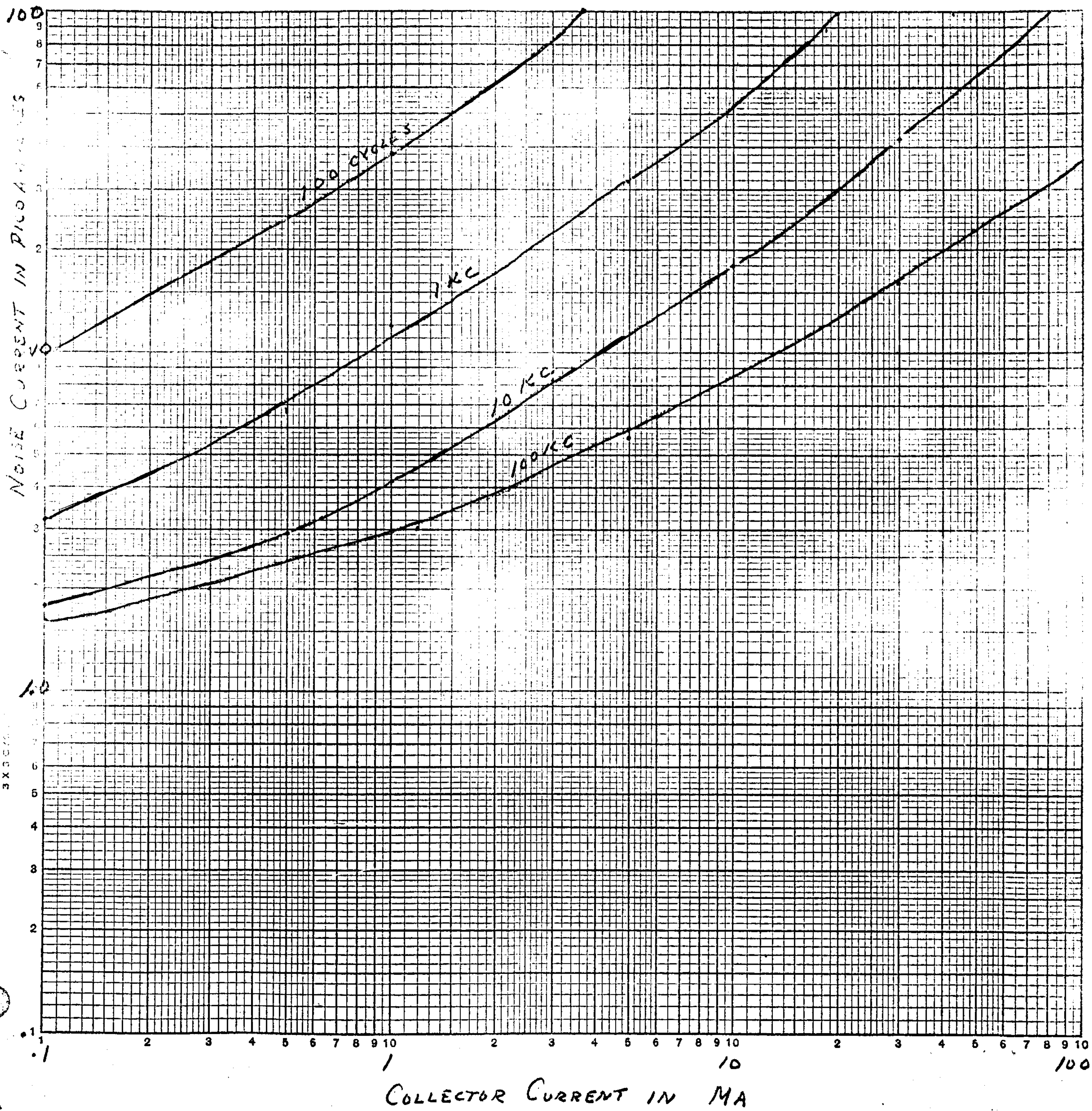


FIG 4.5.1.3 VARIATIONS IN NOISE WITH COLLECTOR CURRENT

Fig. 4.5.1.3 shows a plot of noise variations with collector current. This shows convergance indicating that values under .lmA collector current would be useless at 10 KC and 100 KC. Values at 100 KC would be more useful at the 30 mA range as originally planned, at 1 mA, the 100Ω, 1 KC and 10 KC would be useful.

4.5.2 10 KC Noise

Data on noise and other parameters was examined and calculations made to determine if the 10 KC and the 1 KC noise at high current would produce more useful information than the use of 1 KC noise at two different current levels.

From this study, the amount of data seemed much more valuable at 1,000 cycles. Variations at the 10 KC seemed proportionate to the 1 KC signal at a single current, but the 10 KC would be subjected to greater error due to readability and background noise.

The elimination of 10 KC noise would decrease test time and permit a total of 16 items on a single computor run.

4.5.3 Reading Fluctuations

Operator time proved to be excessive for the programed time of the complete project. Two reasons were found. At low frequencies, the noise meter showed wide fluctuations of reading.

It was necessary to use caution to observe the variations of the meter and mentally average each reading over a few seconds.

This factor will present a serious problem in the production use of any noise measurement.

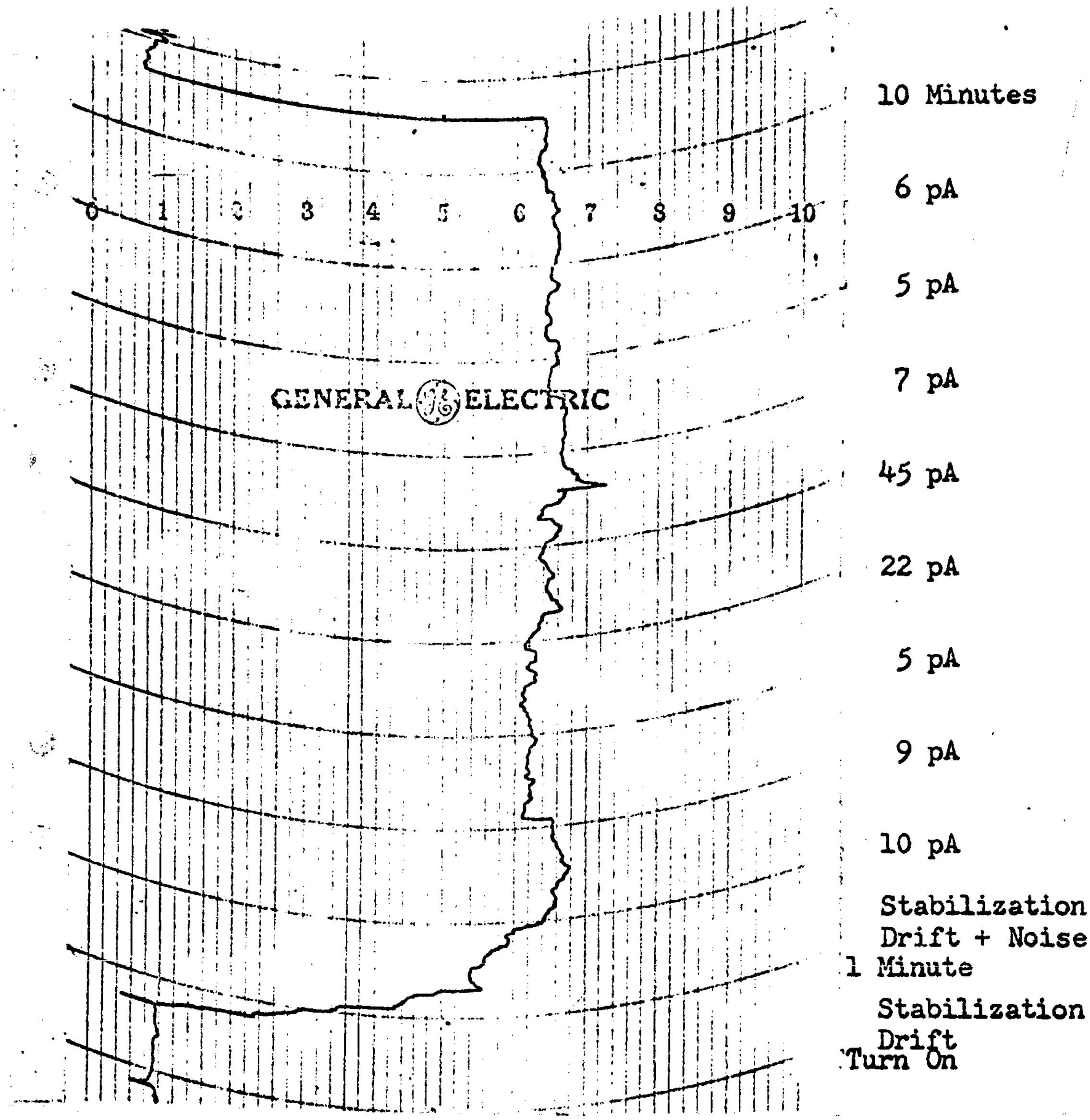
The reason for this fluctuation may be closely associated with failure mechanism and results from the 1/f nature of Flicker noise.

Second reason for delays was because tests were manual and only two pieces of equipment were available to handle this contract plus all other tests.

Fig. 4.5.3.1 shows a dc recording made by the project engineer in 1960 as an interesting detail incidental to the objective of another reliability investigation. The investigation was made in GE but in another department. This curve shows the dc nature of noise on the most obvious of about 100 such traces all of which showed the same effect in lesser amounts.

The trace represents the dc shift at a sensitivity of In = 10 picoamps per division. Scale range is 1 minute per inch. Such a noise reading would show readings from 5 to 45 pA peak during any one minute observation.

Use of equipment of this kind was not possible in this investigation as substantial instrument development costs and capital investment is required.



Sensitivity = 10 pico amperes/div.

FIG. 4.5.3.1 Transistor Noise at 0 Frequency recording made 1960 showing transistor having abrupt shifts in signal. This record was the most pronounced recording of 100 transistors where noise of this nature occured in various amounts.

4.5.4 Suitability of Revised Program

The revised limits and procedures should show with reasonable confidence if a noise test will aid us a means of eliminating units likely to fail.

The changes should improve resolution at the low frequency end without eliminating the distinction between low current and high current.

The increased sample size should permit more useful failure criteria than was possible on the initial experiment.

4.6 Preliminary Results of Noise Experiment

The initial step stress experiment was so limited in sample size and the complexities so great that some acceleration method was necessary to determine the factors necessary for adequate re-design of the future experiment.

4.6.1 End point contraction as an accelerating method.

Much useful information can be expected from the use of restricted end points as a means of gaining knowledge.

The following experiments were conducted by analysis of the data using the following end points. These end points approximated limits between normal initial limits and normal end of life limits as used on life tests generally.

Special Noise Failure Limits

	Min.	Max.
I_{CBO} @ V_{CB} = 5V		20 nA
I_{CBO} @ V_{CB} = 60V		20 nA
I_{EBO} @ V_{EB} = 5V		20 nA
I_{CEO} @ V_{CE} = 5V		20 nA
BV_{CEO} @ Ic = .1 mA	40	V
$V_{CE(SAT)}$ @ I_b = 5 mA, Ic = 50 mA	.08	.375 V
$V_{BE(SAT)}$ @ Ib = 5 mA, Ic = 50 mA	.75	.810 V
h_{FE} @ V_{CE} = 5V I_C = 20 mA	150	350µA*

*Ib for Ic = 20 mA

4.6.1 (Cont.)

The validity of the results obtained by end point reduction is such that the results should not be interpreted as positive or final. However, this technique does simplify the determination of many of the factors involved without large scale experiments.

4.6.2 The combined results of the noise experiments are shown by the following table for each test.

In this table a noise limit was also arbitrarily selected which would represent the upper level of each noise distribution. Thus noise was somewhat out of the indicated noise distribution envelope and represents units which were questionable in noise level.

Noise limits used to classify unit as high noise:

100~5 A	Max. 4.0 pico amperes
1 KC 5 mA	" 2.0 pico amperes
1 KC 30 mA	" 170 pico amperes
10 KC 30 mA	" 60 pico amperes
100 KC 30 mA	" 22 pico amperes

The table shows the step number where the transistor exceeded either the set of limits for being out of limits (contracted limits) or out of normal noise distribution.

Fig. 4.6.2.1 shows the tabulated results of the first step stress lot 100 hour temperature test 343-201.

4.6.2.2 Results if noise is measured at the initial test.

Three units tend to confirm that a noisy unit is an unreliable unit.

No. A33 showed high noise on Test 1 (Initial) and failed h_{FE} on second test (after first 100 hour stress).

No B104 failed initial test at 1 KC and at 10 KC. This unit developed high I_{CBO} at end of first 100 hour of stress. No. C62 showed high noise at first measurement and later developed leakage on the 4th measurement (after 340°C stress).

This shows that three bad units were detected by a noise test, but not by original tests by other means as defined by the 2N718A specification.

4.6.3 Validity of above notes

This analysis leads to several doubts which need further investigation. Each transistor in this lot was submitted to the temperature stress only.

It may have been noisy due to a mechanism which required voltage also or power as covered in the experiments shown in 4.6.4, analysis of the other lots.

There may be several variations of the failure mechanism associated with noise each accelerated by a different stress or combination of stresses.

It is necessary to think in terms of a noisy transistor having a greater probability of failure and not rely for proof the fact that a transistor or small sample did not fail a given experiment.

FIG. 4.6.2.1

Test 343-201, 100 hour tread temperature step stress.

1 = Initial Reading -- 2 = 250°C -- 3 = 300°C -- 4 = 340°C

NO.		← 5 µA →		Number Shows ( ) ← 30 mA →			WHEN NOISE INDICATES FAILURE							
		100 ~	1KC	1KC	10KC	100KC	I_{CBO} 5V	I_{CBO} 60V	I_{EBO}	I_{CEO}	BV_{CEO}	$V_{CE(SAT)}$	$V_{BE(SAT)}$	h_{FE}
erial	Pos.													
A3	1		1											
A7	2													
A33	3			1(2)3	1	1								2
A130	4													
A244	5													
A255	6			3		3								
A257	7													
A300	8			2 3										
A400	9			2										
A426	10													
384	11	1	1 3											
3104	12	3		1(2)3	1			2 3						
3225	13													
3227	14													4
3245	15													
3372	16													
3417	17													
3421	18	1 2 3	3	1 2 3	1 2 3	1								
3463	19												3	
3588	20													
62	21	1 3	3	1 2		1	4	4	4	4				4
83	22	3	(2) 3				3	3	3	3	4		4	4
122	23	3	3	(2)3	(2) 3	(2) 3	3	3	3	3	4	4	4	2 3
132	24	3					4	4		4				
160	25	(2)3	(2) 3	3	3	3	3	2 3	3	3	4	4	3	3
180	26	3	3			3	4	4	4	4				3
405	27	3	(2) 3	3	3		3	3	3	3	4	4	4	3
424	28	3	(2) 3	3	3	3	4	4	4	4			4	4
441	29	(2)3	3	3		3	3	3	3	3	4	4	4	3
599	30	3	3				3	3		3	3	4	4	4

Three units A-3, B84 and B421 showed high noise on the initial test but did not fail due to temperature stress.

4.6.3.2 Noise conditions may require activation before noise becomes useful as a predictor.

If noise conditions are associated with any phenomenon involving surface charges or ionization, it is very possible that noise tests on a unit which has been idle for a long period may not be as useful as a predictor as noise tests made after stresses.

Examination of Fig. 4.6.2.1 shows more units having noise after first stress than before stress.

In this case the units exceeding noise limits and later failing other test limits are shown by the ( ) around No. 2 or step where noise levels are exceeded.

This shows a much better prediction but also is inconclusive because noise detection by this means is mainly improved by detecting process C units which exceeded the limits shown. This can be due to a normal shift of the population or by the fact that these were failing anyhow.

4.6.4 Results as applied to other tests.

In the next test as shown by Fig. 4.6.4.1, there was no units in Process A which showed prediction by noise measurement.

Process B showed some definite trend to confirm detection by either initial test or noise test after first stress.

Process C showed failure of most units (by the definition for this study) and this leads to no definite conclusion.

Fig. 4.6.4.1 repeats the results of the 500 hour temperature only test. In this case, however, voltage plays an important part in the degradation so some different mechanism may be activated.

The remaining tests showed similar inconclusive results though the three processes differed considerably.

Process A almost no predictability.
Process B possibly failure rates would be improved.
Process C failures too high to justify a conclusion.

FIGURE 4.6.4.1

TEST - 343 202 500 hour tread temperature Step Stress

1 = Initial Reading 2 = 250° 3 = 300°C

Number Shows

		← 5 µA →		← 30 mA		→									
rial	No. Pos.	100~	1KC	1KC	10KC	100KC	I_{CBO} 5V	I_{CBO} 60V	I_{EBO}	I_{CEO}	BV_{CEO}	$V_{CE(SAT)}$	$V_{BE(SAT)}$	h_{FE}	Rem
2	1			2 3	3	2									
.15	2			3											
.24	3			2 3	2 3										
.84	4			2 3	1 2										
56	5			3							1 2 3				
45	6			1 2 3	1 2 3	1 2									
70	7			3											
86	8			2 3											
20	9			1 2 3	1 2 3	1 2									
48	10			2 3	2 3	2									
40	11			3									1 2 3		
55	12		2 3	3											
06	13			3											
63	14	1 2	1	1 2 3	2	2							1 2		
46	15			3											
70	16			3											
83	17	1	1	1 2 3	2 3	1 2								2 (open)	
32	18	1	1	1 2 3		1 2							1 2 3		
70	19		1	3											
00	20	1	1	3											
9	21	3		3			3	3		3					
9	22	3	3	3			3	3		3					
01	23		3	3						3	3		3		
09	24	3		2 3								1 2 3			
15	25	1 2 3	1 2	2 3			3	3		3	3		3		
12	26	3	3	3				1							
81	27			3											
83	28	1 2	1 2 3	1 2 3	1 2 3	1 2	3	3	3	3	3	1 2 3	1 2 3		
60	29			2 3		1	3	3		3	3				
75	30	1 2	2 3	1 2 3	1 2 3	1 2								3	

FIGURE 4.6.4.2

TEST - 343 - 203 100 hour temperature + voltage Step Stress

1 = Initial Reading 2 = 250°C + 30V 3 = 300° + 30V

Number Shows

← 5 µA → ←—— 30 mA ——→

rial	No. Pos.	100~	1KC	1KC	10KC	100KC	I_{CBO} 5V	I_{CBO} 60V	I_{EBO}	I_{CEO}	BV_{CEO}	$V_{CE(SAT)}$	$V_{BE(SAT)}$	h_{FE}	Rem
	1			1 2 3											
	2			1 2	1 2	1 2				4					
	3	1 3		1 2 3	1										
	4			1 3	3										
3	5									3					
9	6			2 3	3										
6	7		1 2				4	4		4					
8	8	3													
6	9			3		3						3			
1	10			3	3	1 3									
	11	3		2	3								1 2 3		
	12	1 2 3											1	4	44
	13														
	14	1 2	2			3	3	3		3	3		4		4
8	15		2												
6	16	3	1 3			3		3	4				4	4	44
5	17	2	1 2						3				4	4	4
7	18	2	2									1	1		
5	19					3	4	3	4	4				4	
6	20												4		
	21	1 2	2	3			2 4	2 4	4	2 4				4	
	22	3	3	3			3	3	4	3	4		3	4	
	23	3					3	3	4	3		1		4	
9	24	3	1 2 3	1 2 3	2 3	2	3	3	2 4	3	4			3	44
8	25	1 3	2 3	1 2 3	1 2 3	12 3	2 3	12 3	3	2 3	4			3	44
3	26	2 3	2 3	1 2	1	1	2 3	2 3	4	2 3				4	
1	27	2 3	2 3				2 3	2 3		2 3	2 4				
0	28						4	4	4	3	4				
9	29	3	3				2 3	2 3	4	2 3	4				444
2	30		3				3	3	4	2 3	4	3			4 5

FIGURE 4.6.4.3

TEST - 343 - 204 500 hour temperature + voltage Step Stress

1 = Initial Reading 2 = 250° + 30V 3 = 300° + 30V

Number Shows

← 5 μA → ← 30 mA →

rial	No. Pos.	100~	1KC	1KC	10KC	100KC	I_{CBO} 5V	I_{CBO} 60V	I_{EBO}	I_{CEO}	BV_{CEO}	$V_{CE(SAT)}$	$V_{BE(SAT)}$	h_{FE}	Rem
90	1		2	1 2	1	1 2 3									
12	2														
35	3			3		3		3	3					3	
52	4														
71	5					1 2 3									
08	6			1 2	1 2	3									
23	7			2 3	2	1 2 3									
55	8	1 2													
78	9														
38	10			1 2	1 2	1 3		3		3					
[illegible]	11	1 2 3	2 3												
[illegible]	12		12 3	2		3									
[illegible]	13					3									
[illegible]	14		1												
[illegible]	15														
2	16		3											3	
3	17	3	3												
2	18														
[illegible]	19														
6	20	3	3	1 2 3	1 2	3									
5	21	3	3			3	2 3	2 3		2 3	3				
2	22	3	12 3			3	3	3							
6	23	3	12 3			3	2 3	2 3	3	3	2 3				
4	24	2 3	3			3	2 3	2 3	3	2 3					
[illegible]	25	1 3	3			3									
0	26	3	3	2	2	2 3	2 3	2 3	2 3	2 3				2 3	
2	27	3	2 3			3	2 3	2 3		2 3					
2	28	1 2 3	12 3	1 2		1 3	2 3	2 3	2 3	2 3				3	
9	29	3	2 3	2	2	2 3	2 3	2 3	3	2 3		3		2 3	
5	30	1 2 3		1 2	1 2	3									

FIGURE 4.6.4.4.

TEST - 343 - '05

1 = Initial Reading 2 = 20V + 500mw 3 = 20V + 670 mw

Number Shows

← 5 μA → ← 30 mA →

rial	No. Pos.	100~	1KC	1KC	10KC	100KC	I_{CBO} 5V	I_{CBO} 60V	I_{EBO}	I_{CEO}	BV_{CEO}	$V_{CE(SAT)}$	$V_{BE(SAT)}$	h_{FE}	Rem
38	1			1 3		1									
43	2														
48	3			2 3	3	3									
74	4			2 3											
32	5	1 2 3	1 2 3	1 2 3	2	2									
54	6			1 2 3		3									
67	7		2	2 3	2 3	1 2									
36	8	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3									
70	9														
76	10														
37	11		1	3											
49	12	1													
81	13	3													
12	14			1 2 3									1 2 3		
59	15														
09	16														
33	17	1 2 3													
43	18												1 2		
16	19														
77	20														
2	21	1 3												1 2 3	
8	22						3			3					
5	23			1			2							3	
00	24														
62	25	2	1	2	2 3										
83	26														
99	27														
32	28														
25	29													3	
38	30			1											

FIGURE 4.6.4.5

TEST - 343 - 206 500 hour Power Step Stress

1 = Initial Reading 2 = 20V+ 500 mw 3 = 20V + 670 mw

Number Shows

← 5μA → ← 30 mA →

-ial	No. Pos.	100~	1KC	1KC	10KC	100KC	I_{CBO} 5V	I_{CBO} 60V	I_{EBO}	I_{CEO}	BV_{CEO}	$V_{CE(SAT)}$	$V_{BE(SAT)}$	h_{FE}	Rem
66	1					3									
80	2	3		2		3					1 2 3				
87	3	2 3	2 3	1 2	2	3									
83	4		2 3	1 2 3	1 2 3	1 2 3	2 3	2 3		2 3	3				
09	5					3	2 3	2 3		2 3					
75	6			2		3									
27	7	3	3		3	3				3	3	3	3		open
33	8			1 2	1 2	3									
46	9			1 2 3	1 2 3	1 2 3									
80	10		1 2	2		3									
54	11	3	1 3	2				3	2 3						
31	12	2 3	2 3			2 3			2 3					2 3	
32	13														
34	14		1 2												
38	15		1		1	1 3									
29	16	1 2 3	1 2 3					2 3		3	2 3				
71	17		1			3									
96	18		2 3	3											
65	19														
35	20														
14	21					3									
	22	3	3	2		3									
	23	3	3			3		12 3							
	24														
	25			2 3		3			3						
	26					3						1		1 2 3	
	27					3									
	28	2	2	2		3								1 2 3	
	29					3									
	30	1 3	3			3									

4.6.5 Predictability by Noise Measurement

Three lots (343-202, 4 & 6) were reviewed to determine if this small sample experiment would show evidence of predictability when methods were applied to all three processes simultaneously.

	INITIAL MEASUREMENT			FIRST STEP MEASUREMENT		
	Total	Good	Fail	Total	Good	Fail
Below Max. Limits	52	31 (60%)	21 (40%)	42	30 (71%)	12 (29%)

From this comparison 52 units out of 90 were good by the arbitrary limit. This shows 58% good in the entire lot and 60% good after a noise test was made. This is a very small improvement and has little meaning.

If the noise test were made after the first step, the percentage good increased to 71% from the 58% shown good on the original lot.

4.6.6 Effect of Noise Frequency on Predictability

FIG. 4.6.6.1	INITIAL NOISE					FIRST STEP NOISE				
No. Below Limits	Total Failed Test	Good No.	Good %	Fail No.	Fail %	Total Passed Test	Good No.	Good %	Fail No.	Fail %
100 5 µA	14	6	43	8	<u>57</u>	14	4	28	10	<u>71</u>
1KC 5 µA	19	9	47	10	<u>53</u>	20	8	40	12	<u>60</u>
1KC 30 mA	17	10	59	7	41	37	20	54	17	<u>46</u>
10KC 30 mA	14	11	79	3	21	20	12	60	8	40
100KC 30 mA	15	8	53	7	<u>47</u>	17	8	47	9	<u>53</u>
Normally 58% Good, 42% Bad.										

Figure 4.6.6.1 is a study of the units which failed the noise test. From this study we can see which noise test would select a greater percentage of bad units than good units.

The original lot showed 58% good units and 42% bad. Each per cent underlined showed more than the normal amount of bad units and thus would improve the reliability.

For instance, the 100 cycle noise test at the initial reading had 57% bad units compared with 42% in the lot without noise selection. This would eliminate 15% more bad units than good.

If the test were taken after the first step (second reading), this percentage detected becomes 71% or an improvement of 29%.

Some conclusions from above: The above test or experimental method is still very crude. The limits were chosen only to determine if some correlation existed and are subject to many errors. Some definite statements can be made without further study.

1. Noise frequencies are not equally effective.

2. More effective results can be made by stressing devices prior to noise measurement.

3. Reliability can be decreased by the noise test because more "good" units than bad units will be removed from the lot if the noise test limits or frequency were chosen incorrectly.

4.6.7 For the purposes of this section, the relation between noise and each individual parameter is studied. A more detailed analysis of the relation between noise and each individual failure class will be made after phase III when greater quantities of each failure are available for study.

Fig. 4.6.7.1 is a review of the initial test failures, second test and third test failures vs the noise test taken at the initial time. The number in the body of the table shows the percentage detected of all bad units at the initial noise test and the noise test at the second test.

This table relates the effectiveness in finding the different types of parameter failures.

FIG. 4.6.7.1

ANALYSIS OF ABILITY TO DETECT A PARTICULAR PARAMETER FAILURE BY A NOISE TEST

Lot 343-202, 4 & 6 - 90 Units

FAILURES EXPRESSED AS A PERCENTAGE OF TOTAL IN 3 TESTS

PARAMETER FAILED	NO. FAILED EACH TEST			INITIAL NOISE TEST					SECOND NOISE TEST					% OF UNITS IN LOT EXHIBITING FAILURE
				← 5MA →		← 30 MA →			← 5 MA →		← 30 MA →			
	1	2	3	100~	1KC	1KC	10KC	100KC	100	1KC	1KC	10KC	100KC	
I_{CBO} @ 5V	0	9	15	20	33	20	13	27	33	53	46	27	27	16.6%
I_{CBO} @ 60V	2	11	20	15	30	20	15	25	30	45	50	25	25	22%
I_{EBO} @ 5V	0	4	10	20	40	20	10	20	40	50	60	30	40	11%
I_{CEO}	0	8	14	29	36	29	21	36	43	57	57	36	29	15.5%
BV_{CEO}	2	4	11	27	36	18	18	27	27	36	45	18	18	12.2%
$V_{CE(SAT)}$	2	1	3	0	0	0	0	0	0	33	66	33	33	3.3%
$V_{BE(SAT)}$	4	4	5	60	60	60	20	40	40	20	60	40	60	5.5%
h_{FE}	3	7	11	45	36	36	18	36	45	45	45	27	55	12%

NOTE: Underscored Percentages Show Values Where % is Higher than Percentage of Failures to the Individual Parameter in the Lot. In these cases the noise test would permit improvement of reliability.

FIG. 4.6.7.2

SCREENING EFFECTIVENESS RATIO

This table carries the reasoning of 4.6.7.1 further to show the percentage relation between the original percentage of bad units within the lot exhibiting failure to the particular parameter to the percentage detected by the noise. This is shown by a ratio where 1 is the detection of the same ratio as shown in the initial lot 2, 3, etc. is 2 or 3 times normal expectancy showing better detection of the bad parameter (ex. 100 cycle showed detection of 20% where 16.6% was normal).

INITIAL TEST

PARAMETER FAILED	5 MA 100 ~	5 MA 1KC	30 MA 1KC	30 MA 10KC	30 MA 100KC
I_{CBO} @ 5V	1.2	2.0	1.2	.75	1.6
I_{CBO} @ 60V	.7	1.4	.9	.7	1.6
I_{EBO}	1.8	3.6	1.8	.9	1.8
I_{CEO}	1.9	2.3	1.7	1.3	2.3
BV_{CEO}	2.2	2.9	1.5	1.5	2.2
$V_{CE(SAT)}$	---	---	---	---	---
$V_{BE(SAT)}$	11.0	11.0	11.0	3.6	7.2
h_{FE}	3.7	3.0	3.0	1.5	3.0
TOTAL -	22.5	26.2	21.1	10.0	19.7
AVERAGE EFFECTIVENESS -	2.8	3.3	2.6	1.25	2.5

AFTER FIRST STEP

PARAMETER FAILED	5 MA 100 ~	5 MA 1KC	30 MA 1KC	30 MA 10KC	30 MA 100KC
I_{CBO} @ 5V	2.0	3.2	2.8	1.6	1.6
I_{CBO} @ 60V	1.4	2.0	2.3	1.1	1.1
I_{EBO}	3.6	4.5	5.4	2.7	3.6
I_{CEO}	2.8	3.8	3.8	2.3	1.9
BV_{CEO}	2.3	2.9	3.7	1.5	1.5
$V_{CE(SAT)}$	---	10.0	2.0	10.0	10.0
$V_{BE(SAT)}$	7.2	3.6	11.0	7.2	1.0
hFE	3.8	3.8	3.8	2.6	4.5
TOTAL -	23.1	33.8	34.8	29.0	25.2
AVERAGE EFFECTIVENESS -	2.9	4.2	4.4	3.6	3.2

TABLE 4.6.7.2

Screening effectiveness ratio shows several interesting facts:

1. At 10KC, 30 MA, noise test of units showed less noise for units which failed I_{CBO} at 5 & 60 volts and I_{EBO} or more quiet units than noisy units failed. In general, there was only a small improvement 1.25 times as many noisy units in the combined rejects as there were in the original sample.

2. $V_{BE(SAT)}$ shows some substantial correlation indicating that 11 times as many units were noisy in the failures as in the original population. The quantities of failed units are small, however, giving a lower confidence factor for this conclusion.

3. Referring to paragraph 4.5.1, the 100 cycle noise was expected to be ineffective due to sensitivity of the reading. It does prove to be almost as effective as the two 1KC noise at the initial test but less effective later. The effectiveness is expected to improve on later tests due to a change in procedure using 1 MA for 100~. This may become as effective as other tests.

4. The effectiveness of the 100~tests at the initial reading is the same as at the first step reading. This may indicate that it will be the most useful when improvements are made.

4.6.8 The 100 cycle noise test comparison for the 3 processes:

Fig. 4.6.8.1, 2, & 3 show the distribution of values found on the initial reading of units which did not exceed the test limits and units which did exceed these limits.

The three graphs show percent at or above the various noise levels.

Each curve shows effects which tend to substantiate the theory outlined in Section 4.3.5. If flicker noise is due to a component which is due to factors which are not associated with degradation, and also with factors which can be associated with degradation, we would expect results similar to the results shown in the three graphs.

All three graphs tend to show that there are two different distributions. One mechanism produces a distribution which shows:

Process A 1% of units greater than 33 pico amps.

Process B 1% of units greater than 34 pico amps.

Process C 1% of units greater than 37 pico amps.

This is as shown by the dotted line extension of the major part of the distribution.

Superimposed on this distribution is noise possibly generated by another mechanism.

Process A has a much smaller percentage of units which are included in the second distribution which possibly can be identified by a noise - degradation relationship.

Any study to determine the validity of the use of noise as a screening mechanism would require much greater sample sizes to produce the same validity for Process A than for Process B or C.

Process B distribution shows a marked difference in the distribution of the bad units from any other distribution. This may be caused by the noise producing degradation mechanism being present in all transistors which failed. In the case of the Process C transistors, the degradation type of noise may not be present to a noticeable degree because degradation occurs from a mechanism which produces no noise.

Process A units show too small a percentage of units which are bad due to any conditions to clearly show any effect.

The frequent reports of experiments relative to noise as a predictor tend to indicate a lack of correlation. In this case, a small correlation exists on Process B but not on other units.

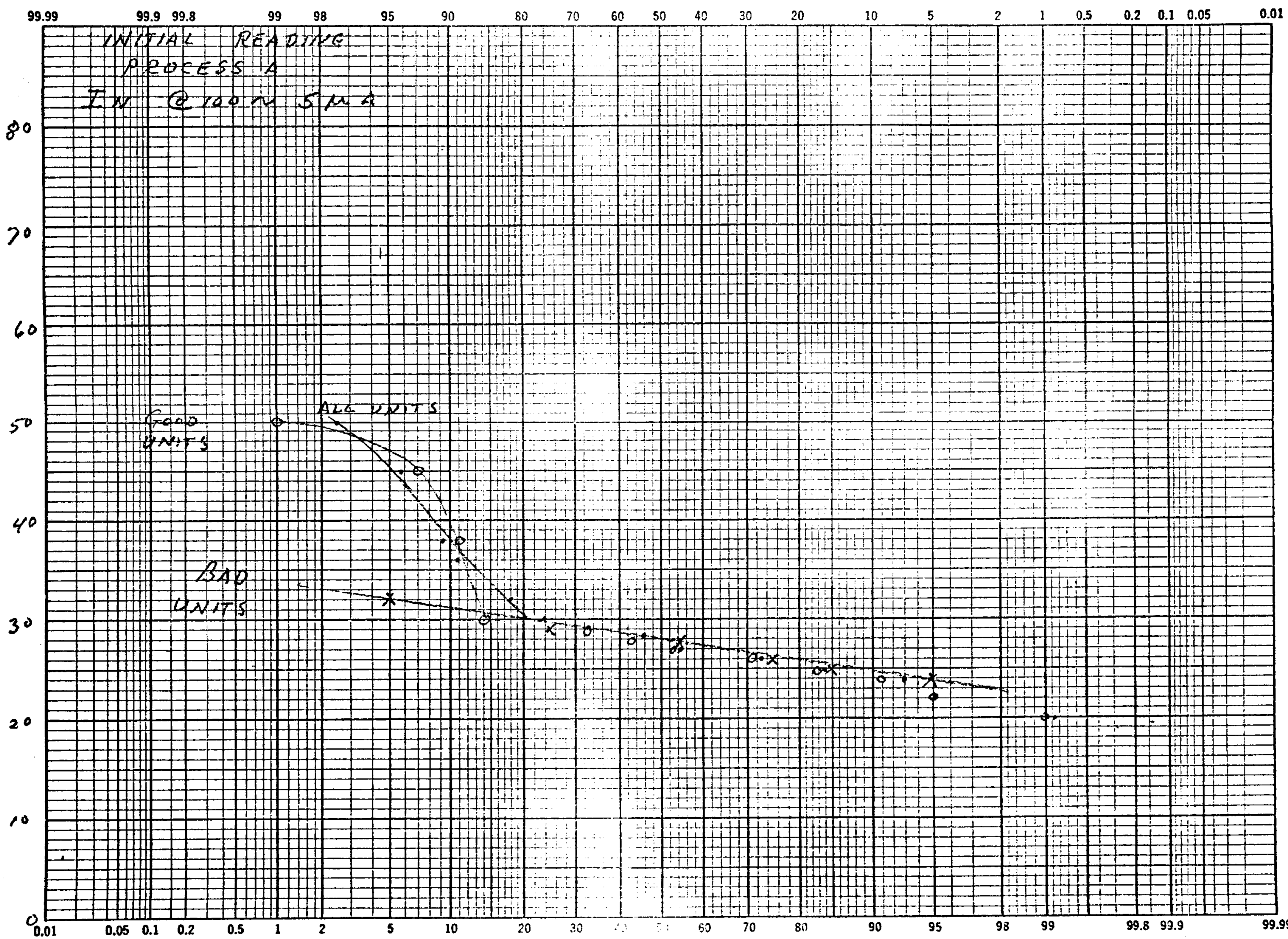

INITIAL READING
PROCESS A
IN @ 100 mm 5 μA
GOOD UNITS
ALL UNITS
BAD UNITS
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
80
70
60
50
40
30
20
10
0

FIG 4.6.8.1

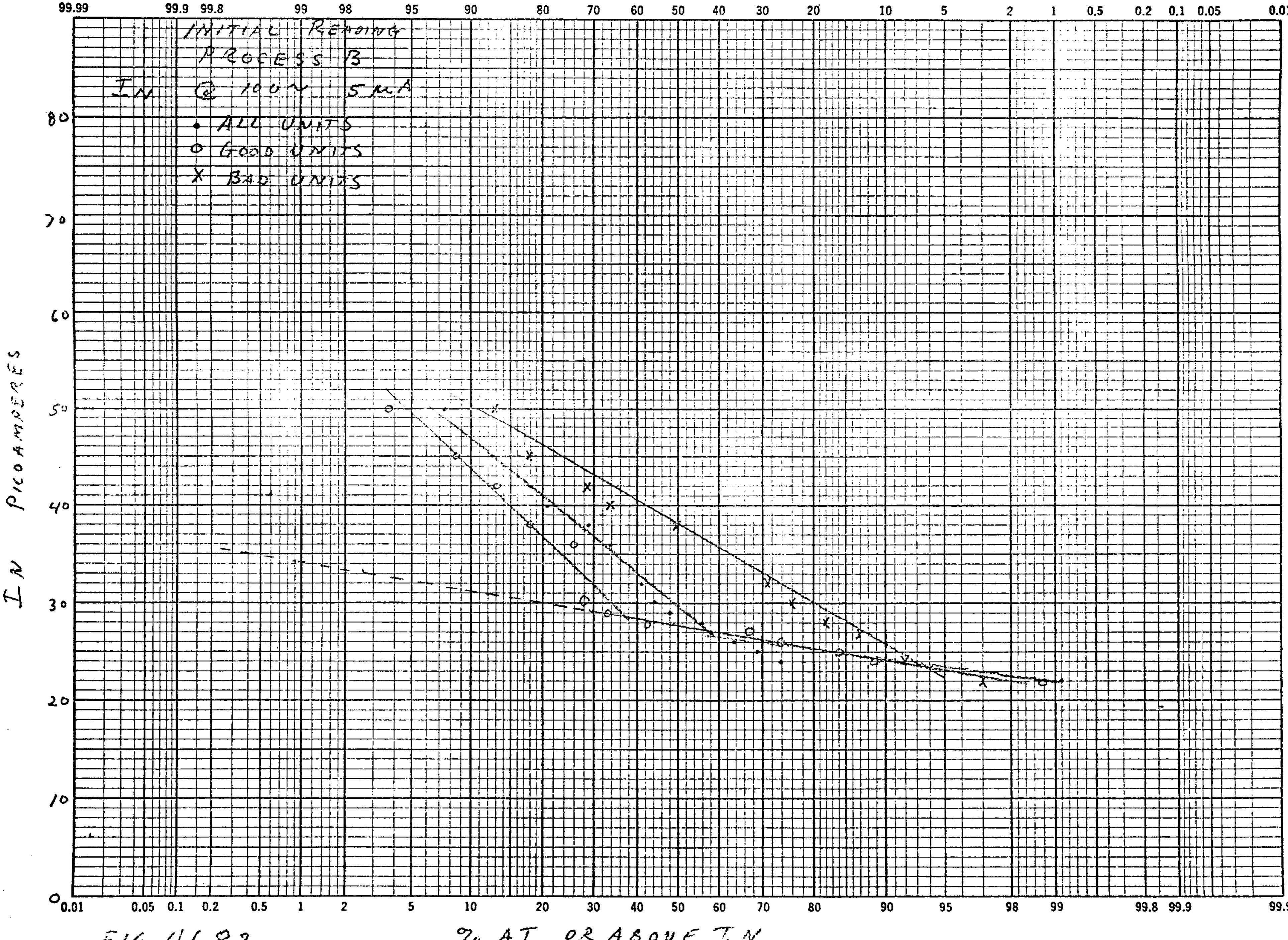

INITIAL READING
PROCESS B
IN @ 100V 5μA
• ALL UNITS
o GOOD UNITS
X BAD UNITS
IN PICOAMPERES
% AT OR ABOVE IN

FIG 4.6.8.2

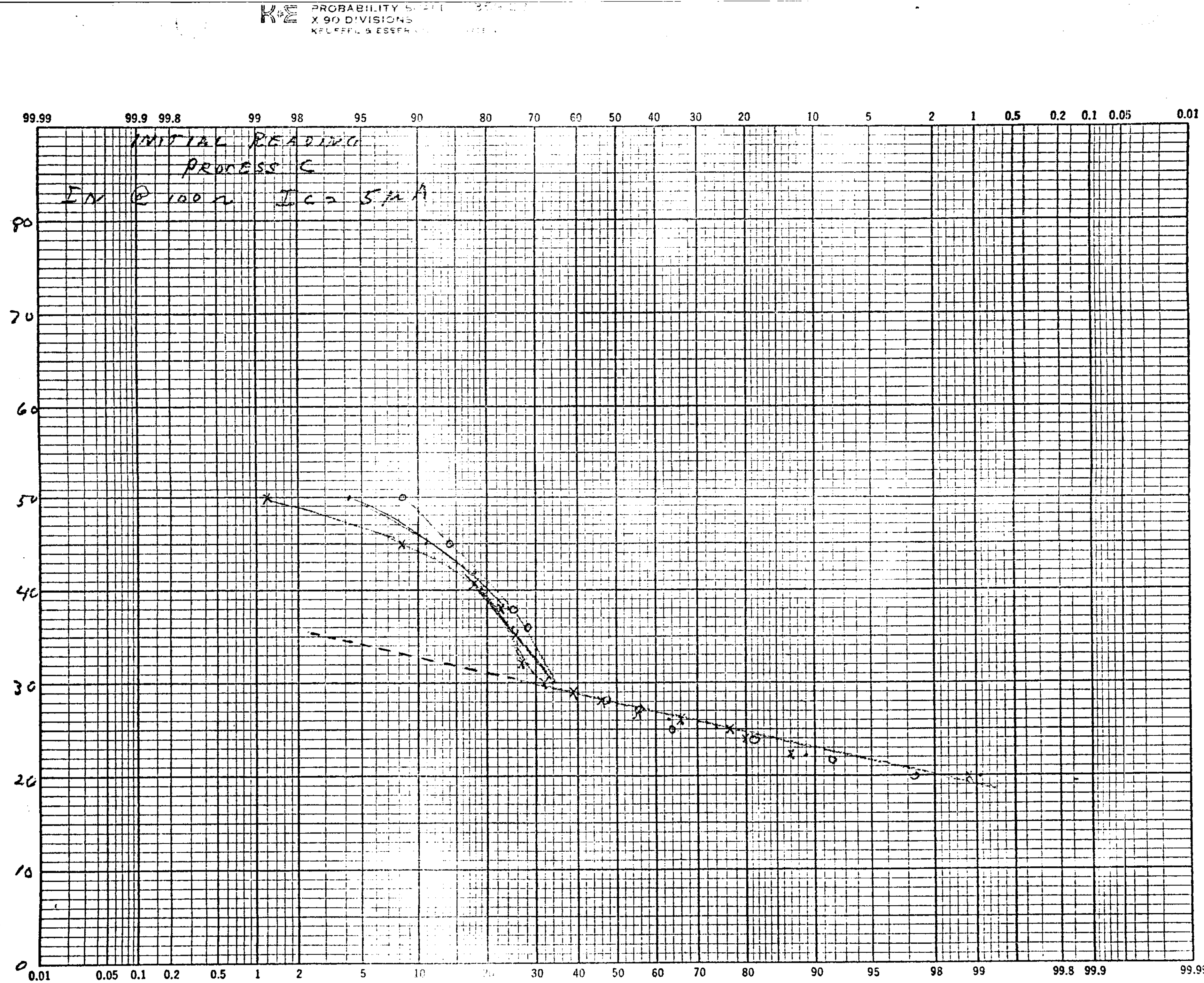


FIG 4.6.8.3

% ABOVE IN

4.6.9 Effect of 1,000 ∼ 5 μA Noise Test

Fig. 4.6.9.1, 2, & 3 show the same comparison for Process A, B, and C when measured at 1,000 ∼ 5 micro ampere.

In both cases, Process A and Process C, there is little if any discrimination between good and bad transistors.

Process B, however, does show the difference found at 100 cycles.

This curve though crude due to a small sample size does indicate that screening to a noise level would improve failure rate for instance screening to 22.5 pico amperes would discard 12% of all units and eliminate 26% of the failures.

There was no indication of an improvement possible from selection of either Process A or Process C as shown on Fig. 4.6.9.1 & 3.

K+E PROBABILITY SCALE 359-23
X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

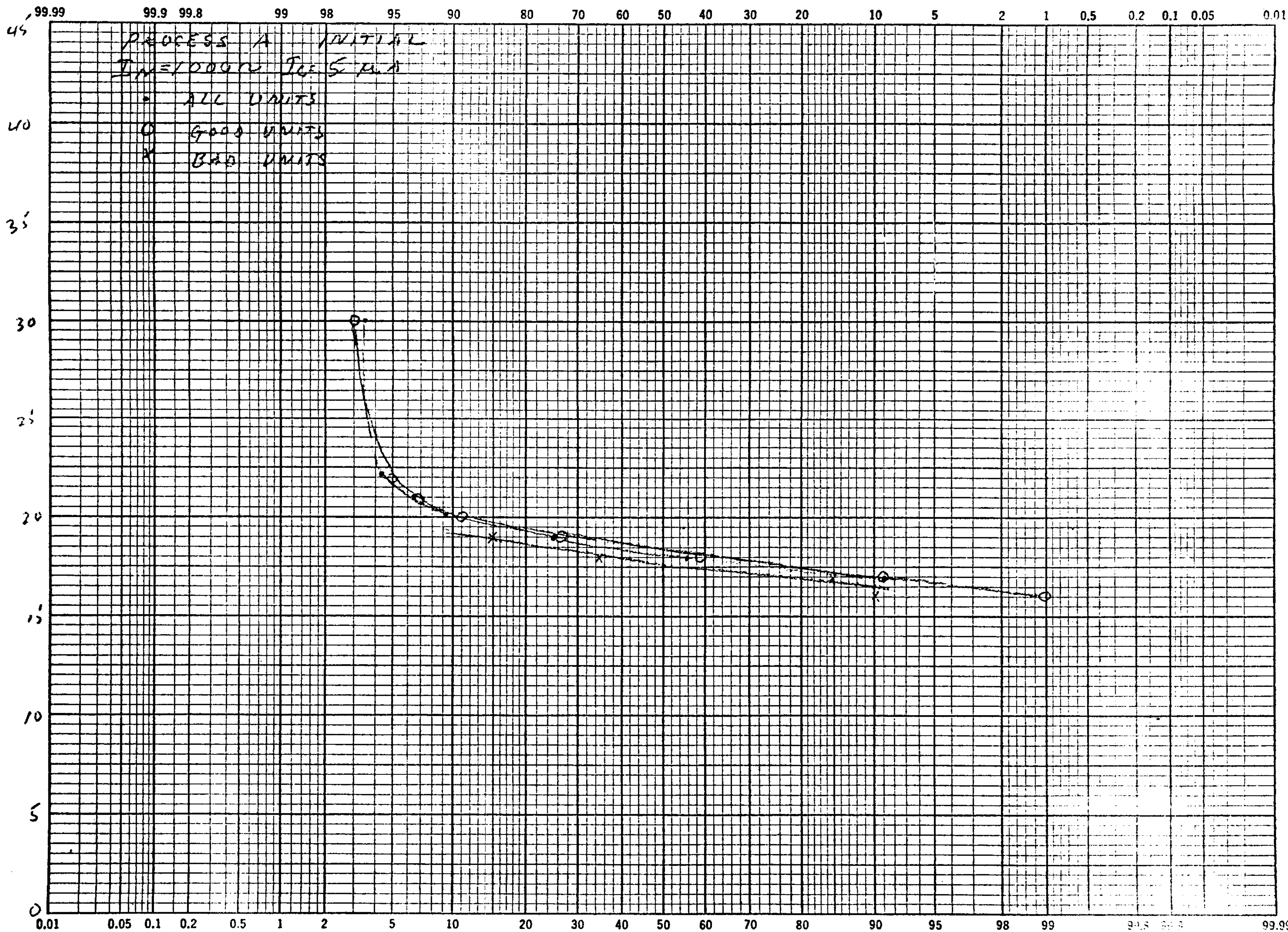
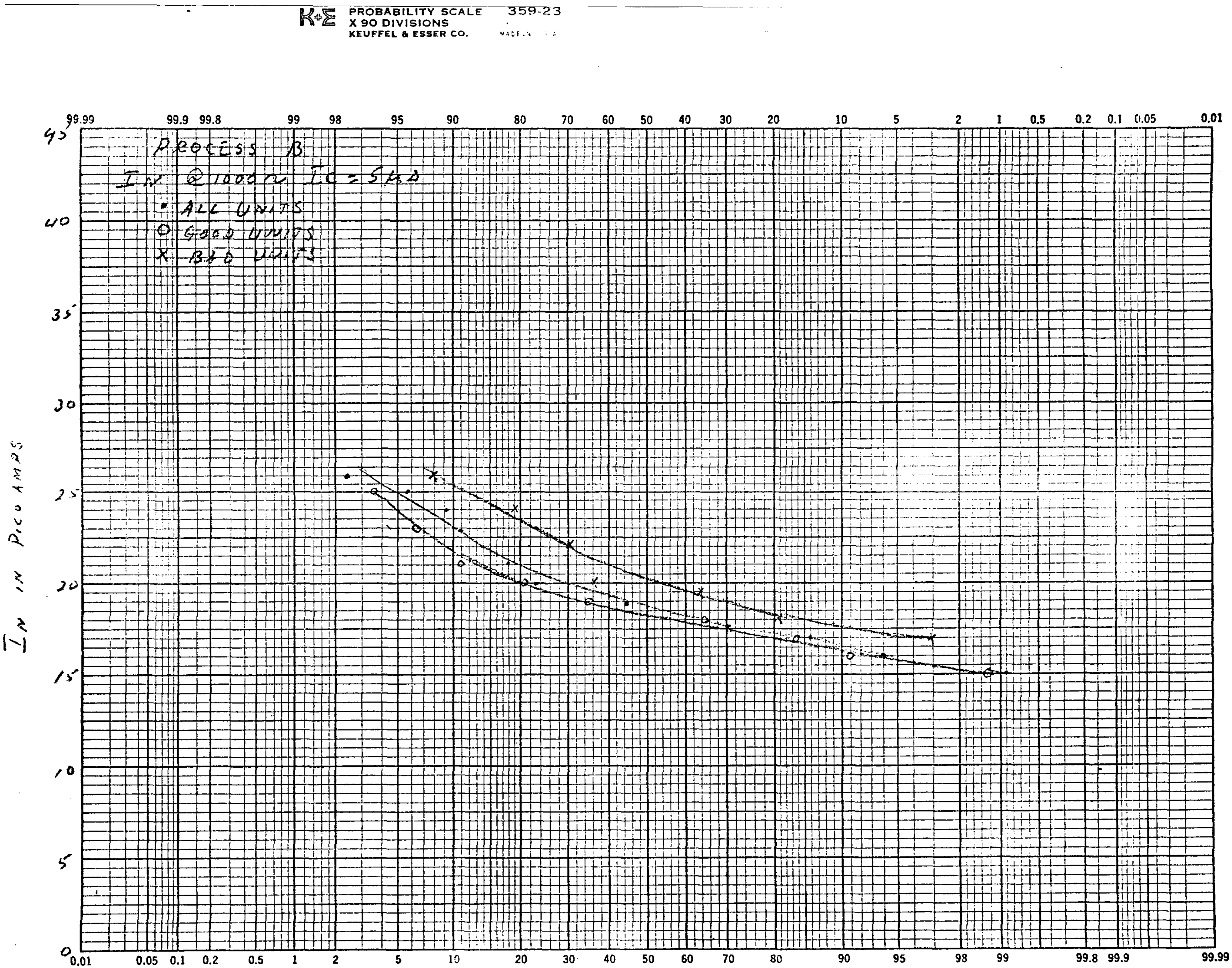


FIG 4.6.1



K+E PROBABILITY SCALE 359-23
X 90 DIVISIONS
KEUFFEL & ESSER CO.
PROCESS B
IN @ 1000Ω IC = 5μA
• ALL UNITS
O GOOD UNITS
X BAD UNITS
IN IN PICO AMPS

Fig 4.6.9.2

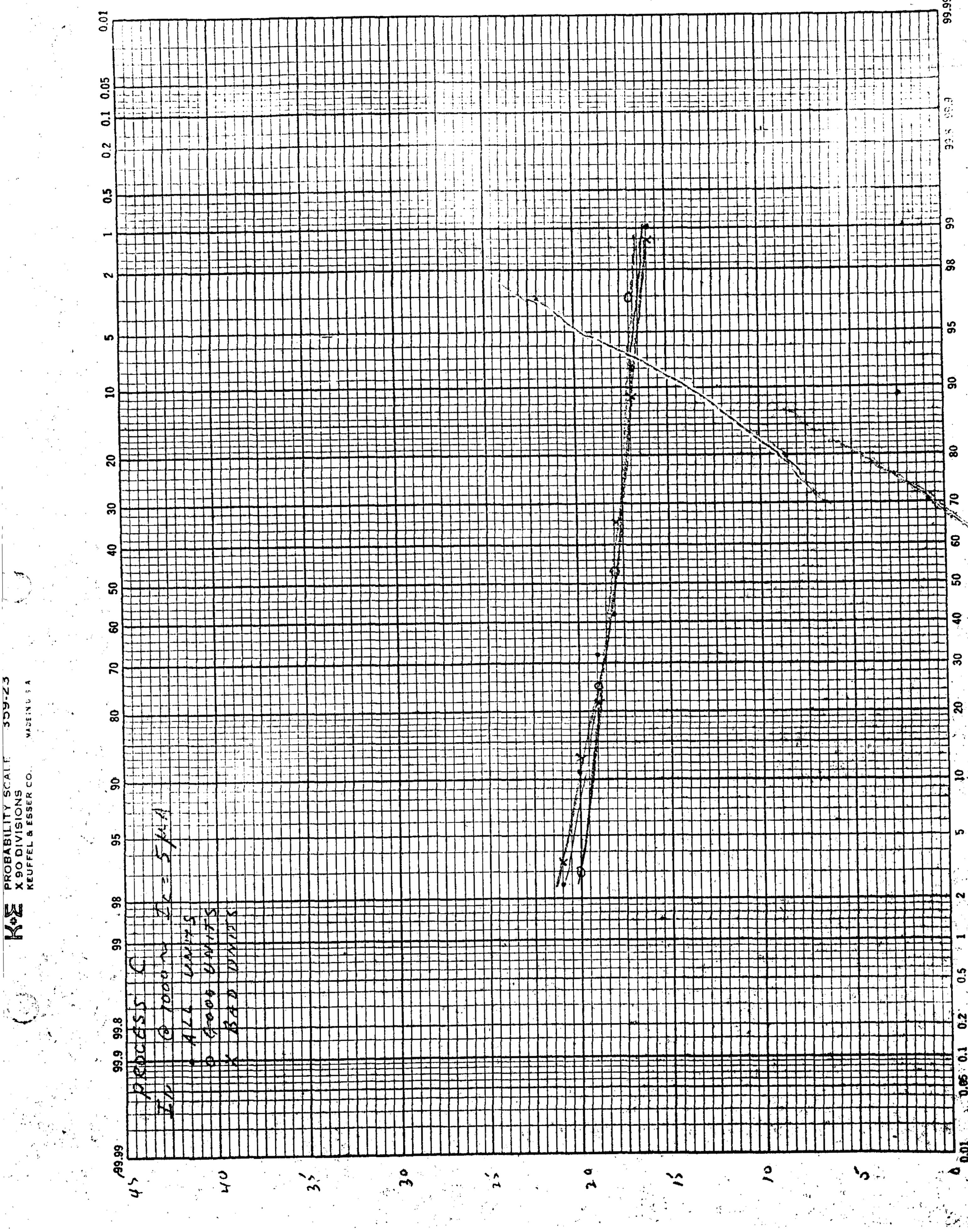

PROBABILITY SCALE 359-23
X 90 DIVISIONS
KEUFFEL & ESSER CO.
MADE IN U.S.A.
PROCESS C
IR @ 1000 h IC = 5μA
• ALL UNITS
○ GOOD UNITS
x BAD UNITS
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
45
40
35
30
25
20
15
10
5
0

FIG 4.6.3

4.6.10 Effect of Higher Current In @ 30 MA 1,000

Fig. 4.6.10.1, 2, & 3 show the distribution of the three processes at 1,000~, 30 MA.

This change shows no improvement over tests made at 5 microampere.

Two new sources of measurement error are introduced, however. These would explain the apparent poor shape of the distribution curve.

1. Readings made below 100 are made on the 1 scale of the meter. Readability of 1 division plus accepatble error 5% of full scale would show only a small number of readings too high or low. Readings made between 100 and 150 are made on low end of the 3 scale where percentage accuracy of ± 20% would be within the guarantee.

2. The 30 MA also introduced heating. If the operator paused to manually shift scales, the noise might be greater on the average due to the delay causing higher temperature.

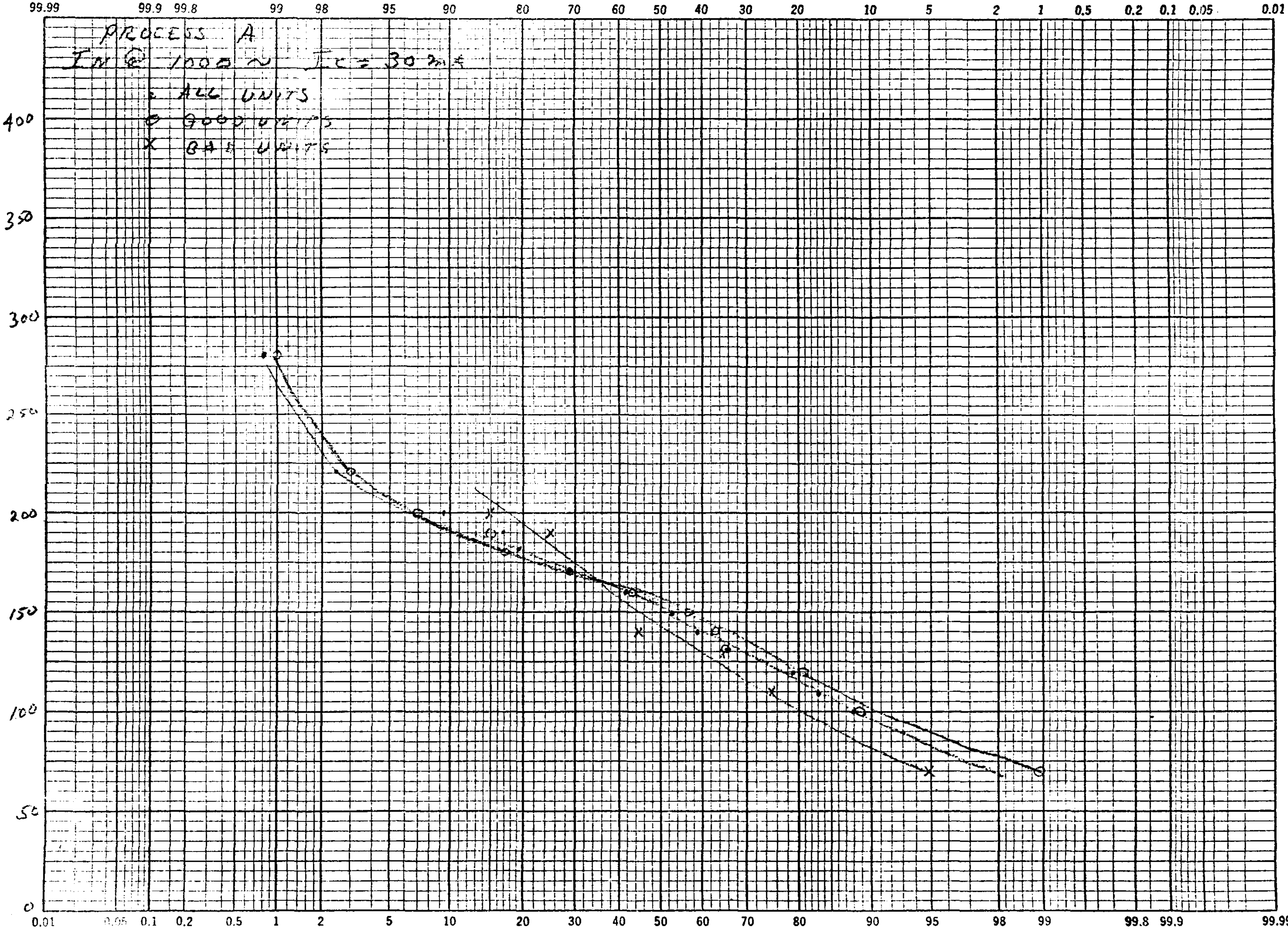

PROBABILITY
X 90 DIVISIONS
KEUFFEL & ESSER
PROCESS A
In @ 1000 ~ Ic = 30 mA
• ALL UNITS
O GOOD UNITS
X BAD UNITS
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
400
350
300
250
200
150
100
50
0

FIG 4.6.10.1

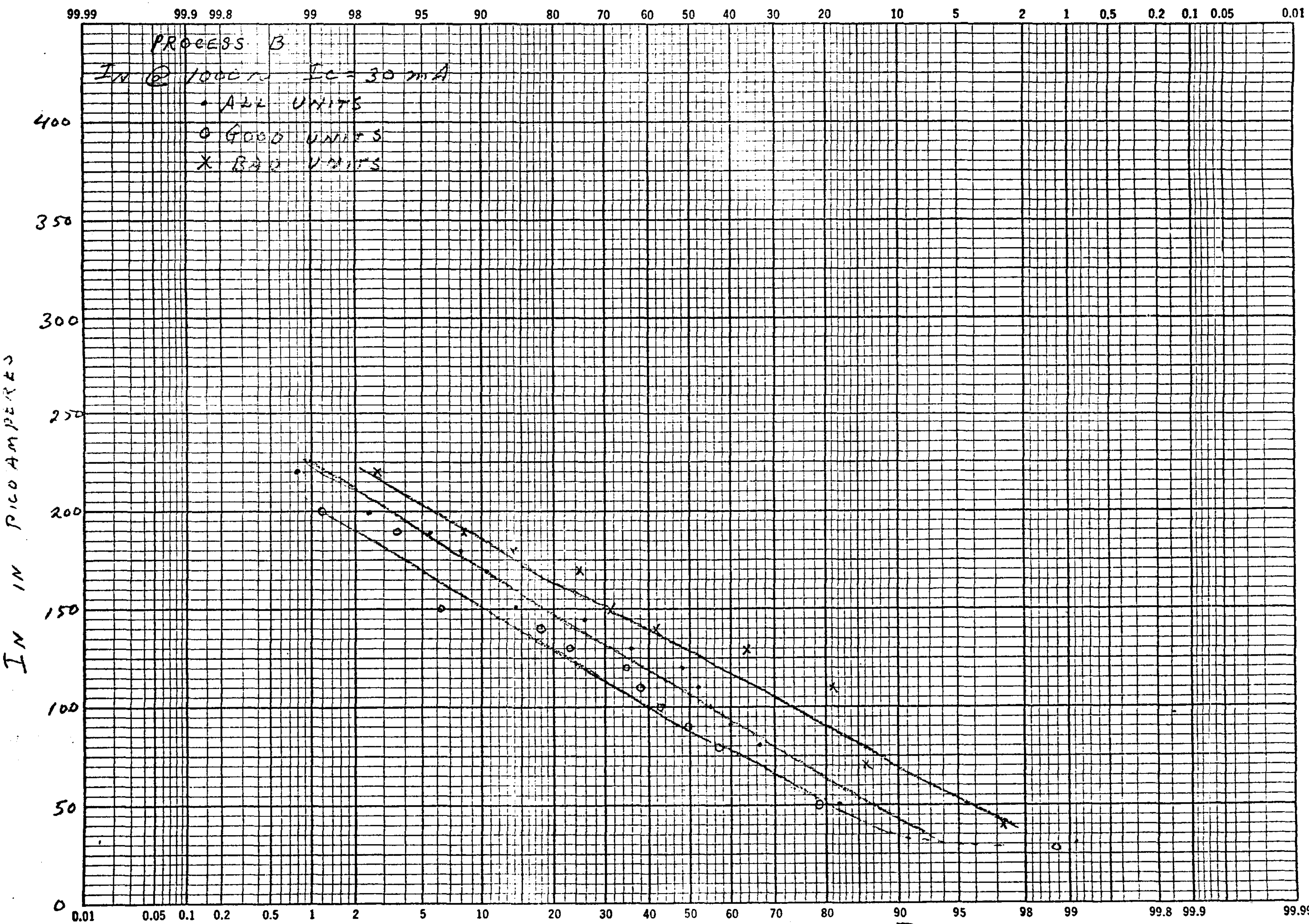


FIG 4.6.10.2 PERCENT OF UNITS AT OR ABOVE I_N

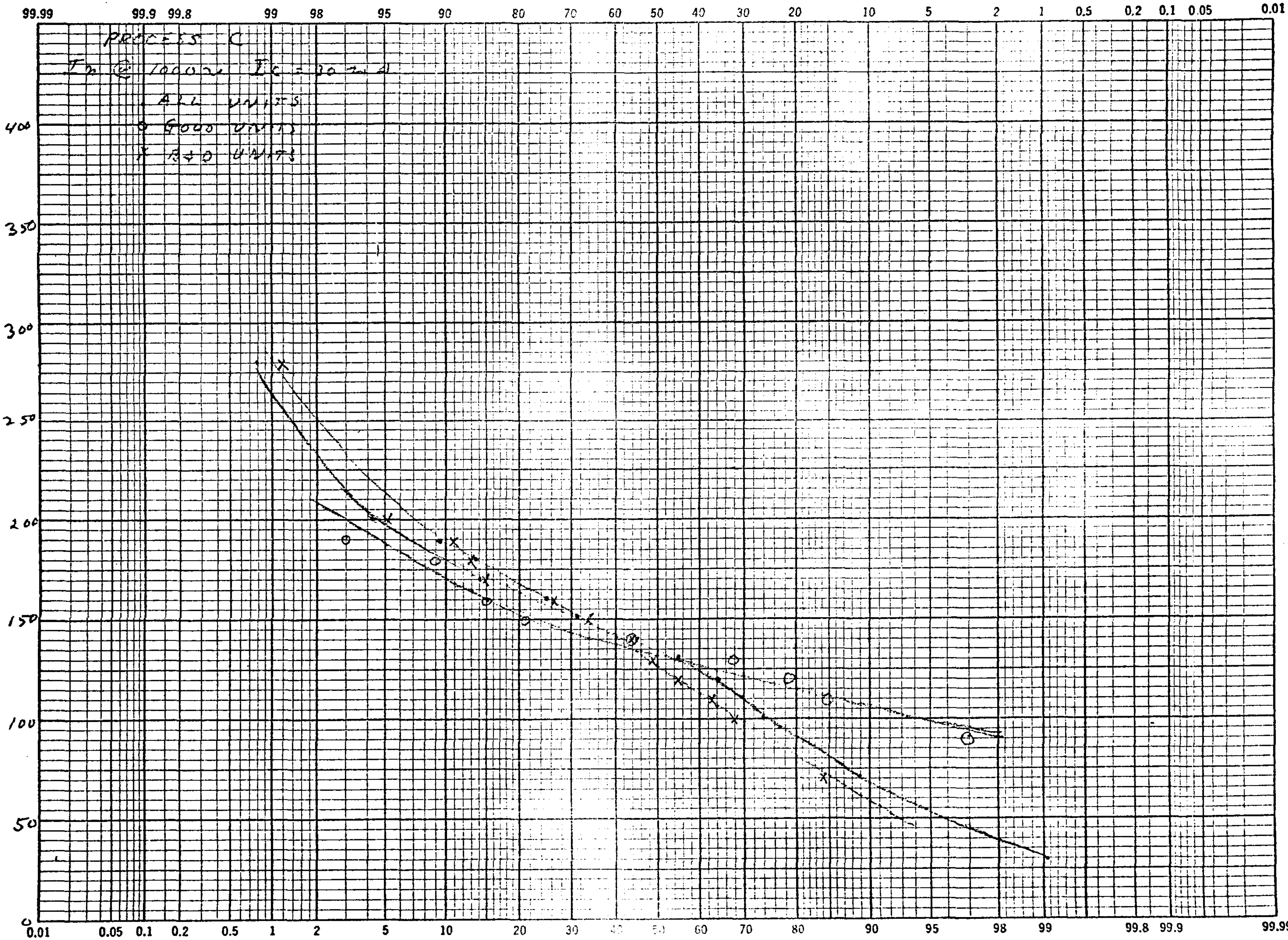

PROCESS C
In @ 1000 Ic = 30 mA
• ALL UNITS
o GOOD UNITS
x BAD UNITS
400
350
300
250
200
150
100
50
0
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG 4.6.10.3

4.7.1 Improvement possible by screening to a noise limit.

Fig. 4.7.1.1 shows the overall result of screening transistors to a noise limit.

Process A and Process C contain a percentage of units that do not show an overall gain when screened to noise limits.

Such gain can be concealed for three different reasons to be investigated further:

1. The percentage of units within the distribution and detectable by a noise test may be too small to be seen in the the quantities involved in this experiment. See paragraph 4.6.8.

2. The failures for other reasons may be too frequent to detect the changes due to a small percentage.

3. If the noise mechanism is some phenomenon involving trapping of ions on the surface, the transistor would need a voltage or high temperature or some other stress mechanism to activate the surfaces before the noise mechanism becomes active.

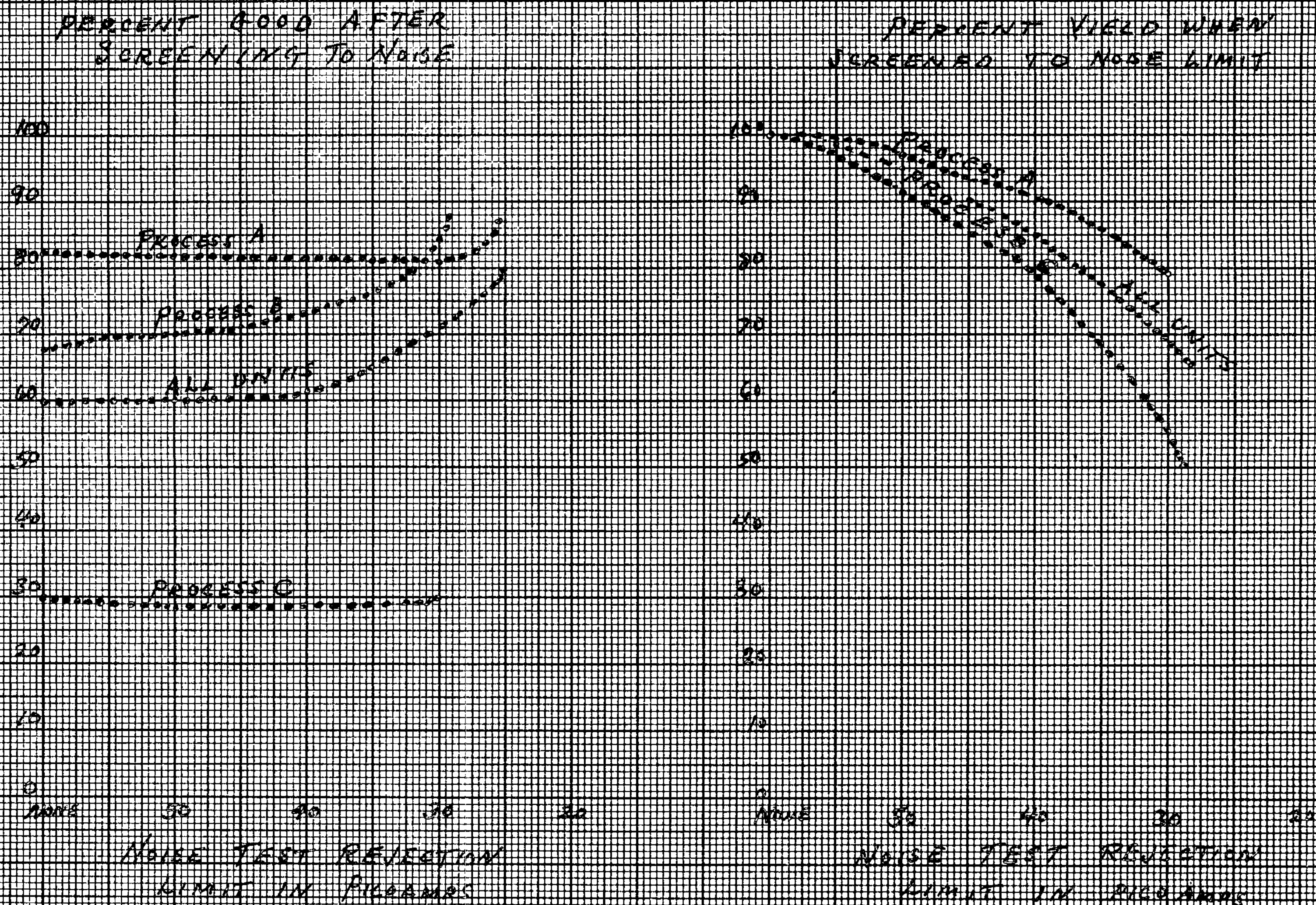


FIG. 4.7.1.1 EFFECTS OF SCREENIGN TO INITIAL NOISE TEST

4.7.2 Effect of Noise Test after First Stress

Fig. 4.7.2.1 shows the effect of the noise test after activation.

The percent good on all units has increased from a maximum of 86% good after screening the Process B units to a maximum of 95% after screening.

The same screening did not show an improvement in Process A or Process C.

This experiment does show that screening to a noise test limit can detect failures but an improvement in the ability to detect will occur if noise test is made after the unit has been stressed.

As previously stated, failures may be detected in Process A or Process C by the above mechanism but due to either a small number of failures for the specific cause or for a large number of failures due to some other cause, the effect may be concealed.

FIG 4.7.2.1 EFFECTS OF SCREENING TO A NOISE TEST AFTER FIRST STEP

4.7.3 Effects of Noise Test after First Stress

Fig. 4.7.2.1, 2, & 3 show the overall effects of making noise tests after one stress level. The analysis here differs from 4.7.2 in that failed units are plotted as a distribution of percentage of units vs noise level for failed units only.

Process A now shows a much clearer difference between good and bad units and the noise relation than was shown on initial readings (see 4.6.8.1). No change seems to take place in the median values. The very few failure units tend to indicate a relation between failure and noise.

Process B now shows a definite difference in distribution for units which fail and those which do not.

Process C now also shows an improvement in ability to detect a failure.

All 6 graphs show a very similar basic distribution with a second superimposed distribution.

In the case of Process A the effects of the secondary noise source are evident in 12% of the units. In B the effect is evident in 34% of the units and in C the effect is evident in 45% of the units.

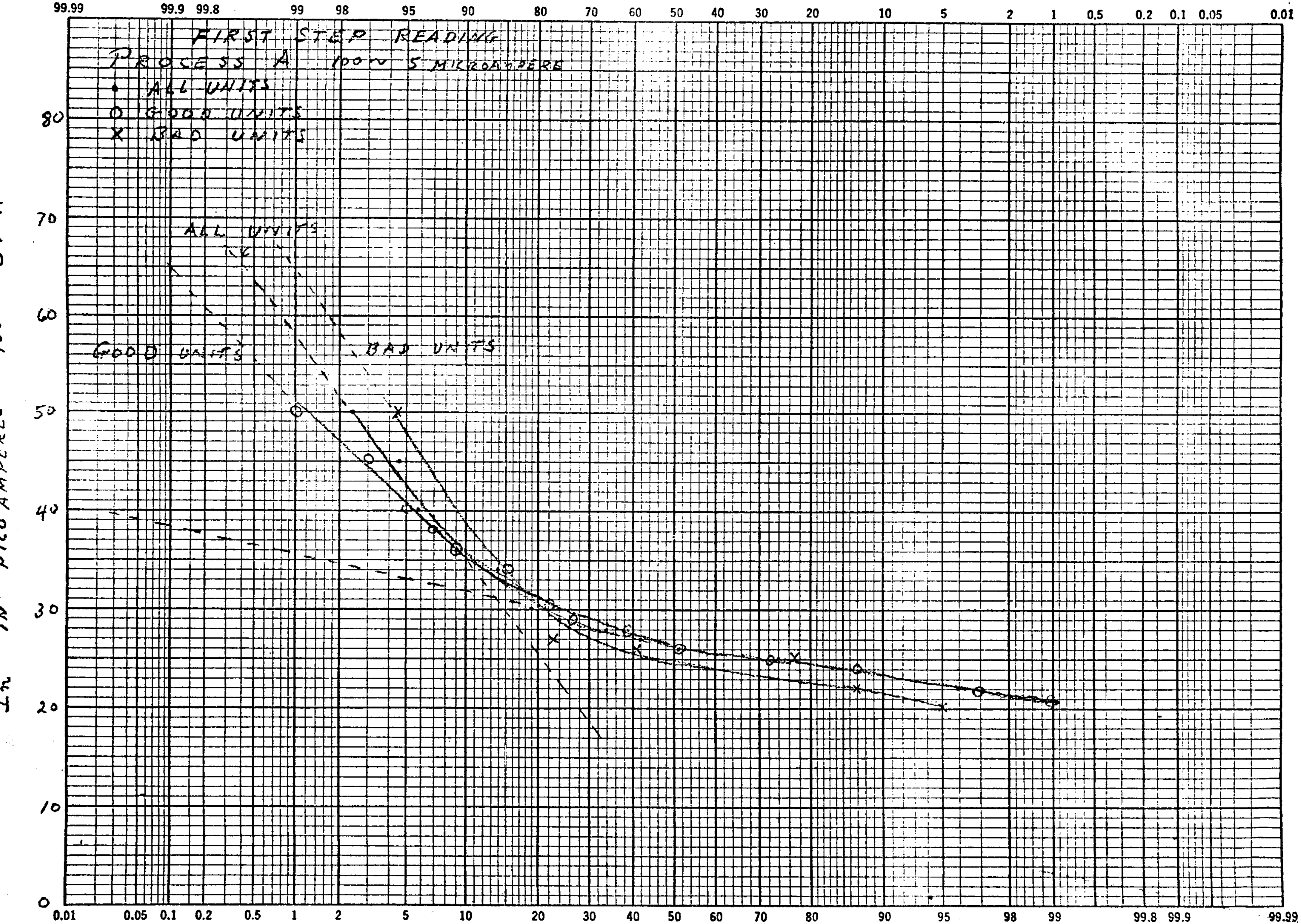

FIRST STEP READING
PROCESS A 100 ~ 5 MICROAMPERE
• ALL UNITS
O GOOD UNITS
X BAD UNITS
ALL UNITS
GOOD UNITS
BAD UNITS
I_n IN PICO AMPERES 100 ~ 5 MA
PERCENT OF UNITS AT OR ABOVE I_N

FIG 4.7.3.1

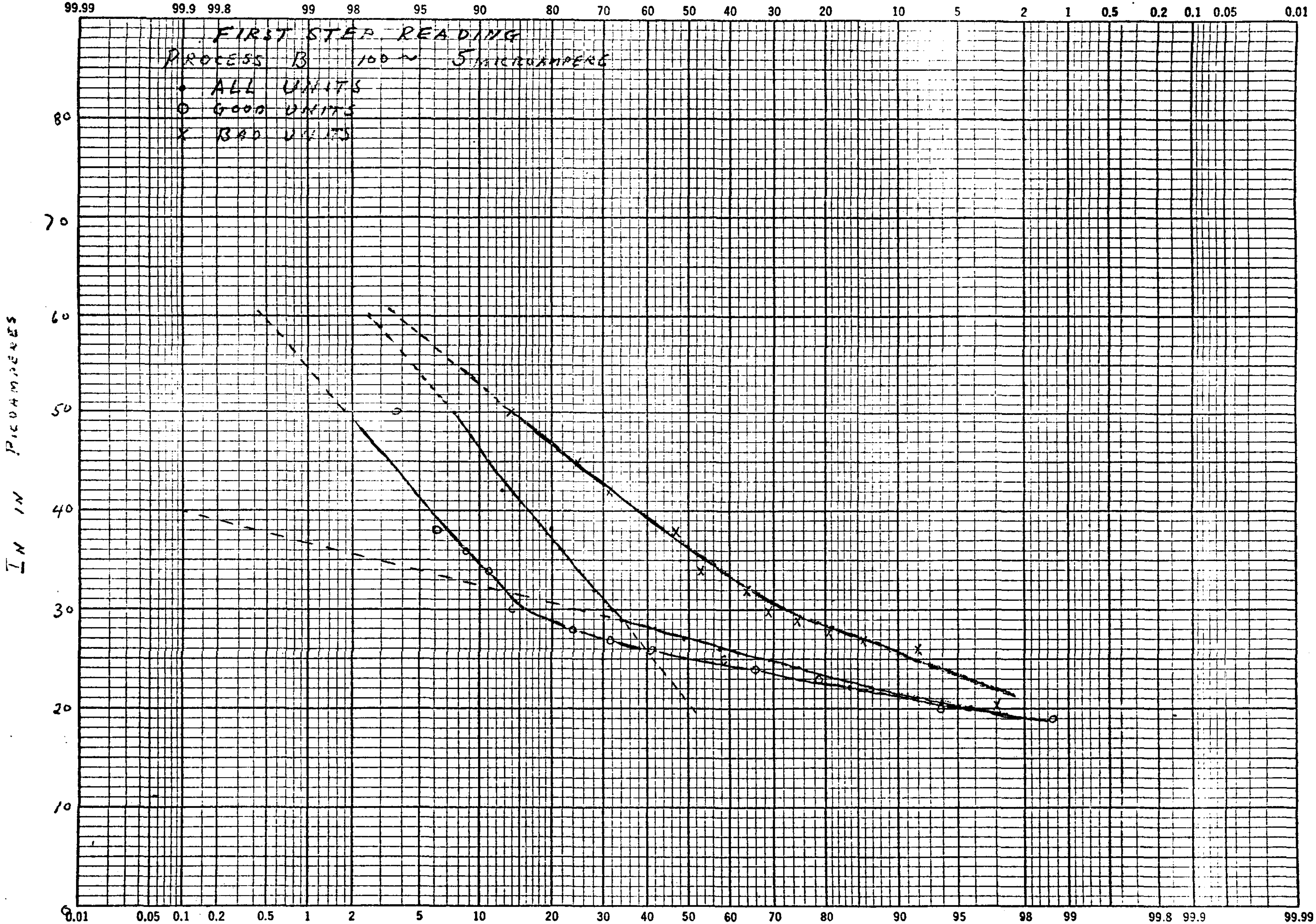


FIG 4.7.3.2 PERCENT OF UNITS AT OR ABOVE IN

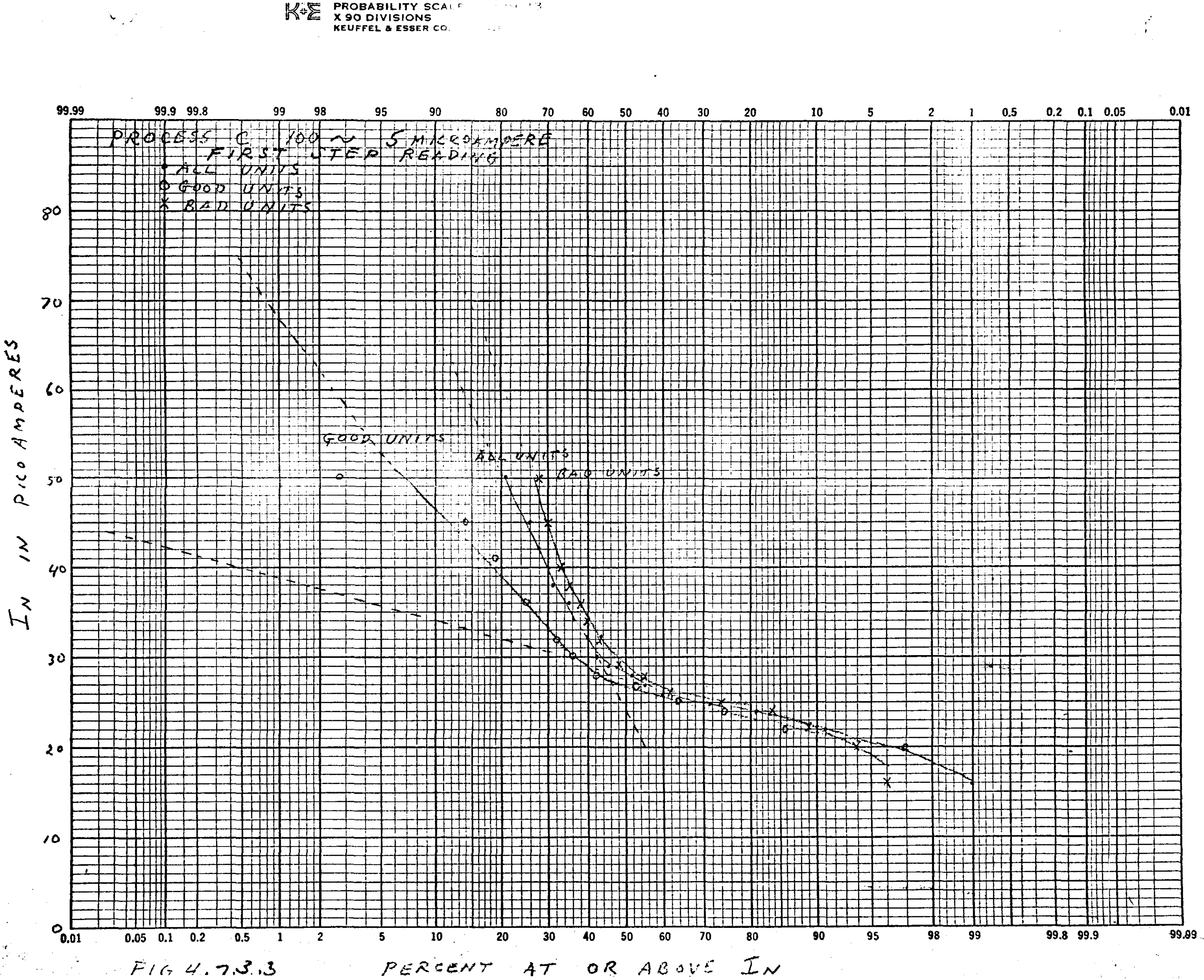

K+E PROBABILITY SCALE
X 90 DIVISIONS
KEUFFEL & ESSER CO.
PROCESS C 100 ~ 5 MICROAMPERE
FIRST STEP READING
• ALL UNITS
o GOOD UNITS
x BAD UNITS
GOOD UNITS
ALL UNITS
BAD UNITS
IN IN PICOAMPERES
PERCENT AT OR ABOVE IN

FIG 4.7.3.3

4.8 Failure Mode vs Noise

Comparison was made between the cumulative percentage distribution of units which failed various parameters and the cumulative percentage distribution of all units in the 3 lots 343-202, 4 & 16. The 100 cycle 5 micro amp noise was used.

Curve 4.8.1.1 and 4.8.1.2 shows the comparison between the distributions.

If we use the cumulative percentage distribution of all units as a reference, several interesting facts can be observed.

1. The 50th percentile of units which failed IEBO is noticeably higer than the 50th percentile of all units. This tends to confirm that units which fail have more noise. A comparison made at the 90th percentile shows lower noise for units which fail than for all units. Comparisons made using units which had the highest noise would then tend to deny the theory that noise can be used to predict failures.

2. The 50th percentile of units which failed ICBO shows little difference from the distribution of all units. In general there is little detectable difference.

3. At the 50th percentile of units which failed h_{FE} there is a definite difference tending to show that noise tests could detect units which will fail. The units, however, which showed the highest noise did not necessarily fail. This again is contradictory evidence.

4. The units which failed VCE (sat) show no difference in noise other than evidence that in general they tended to have less noise.

5. The units which failed BVCEO did show that a percentage had higher noise, but analysis of the results of the 50th percentile would show no results analysis at the 90th percentile would tend to deny the theory.

When the entire distribution is examined, these curves do tend to confirm that noisy units are more likely to fail. However, it is easy to see how little or contradictory results could be obtained using various analysis methods.

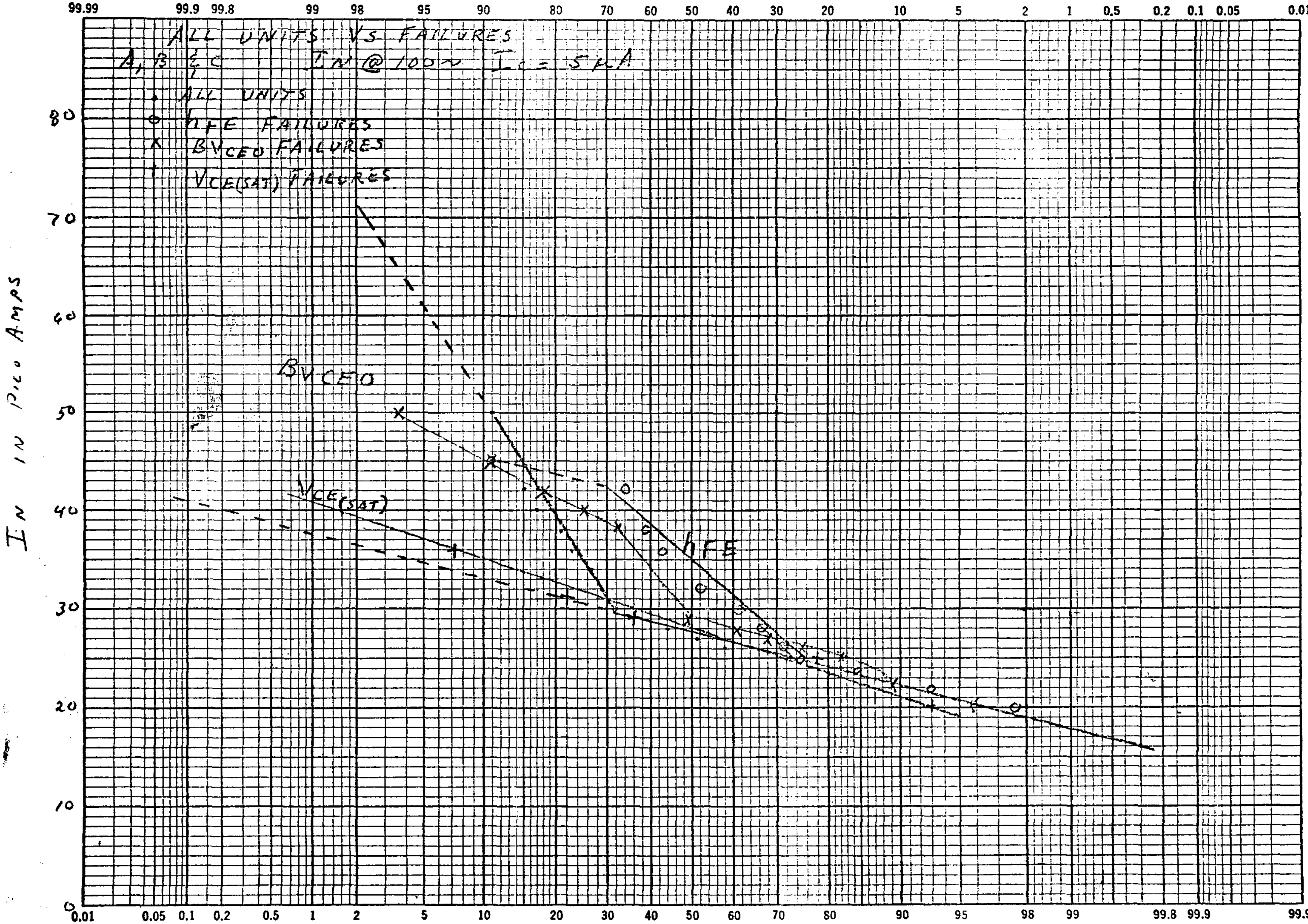

ALL UNITS VS FAILURES
A, B & C   IN @ 100~ IC = 5μA
• ALL UNITS
o hFE FAILURES
x BVCEO FAILURES
ǀ VCE(SAT) FAILURES
BVCEO
VCE(SAT)
hFE
IN IN PICO AMPS
PERCENT OF UNITS AT OR ABOVE IN

FIG 4.8.1.1.

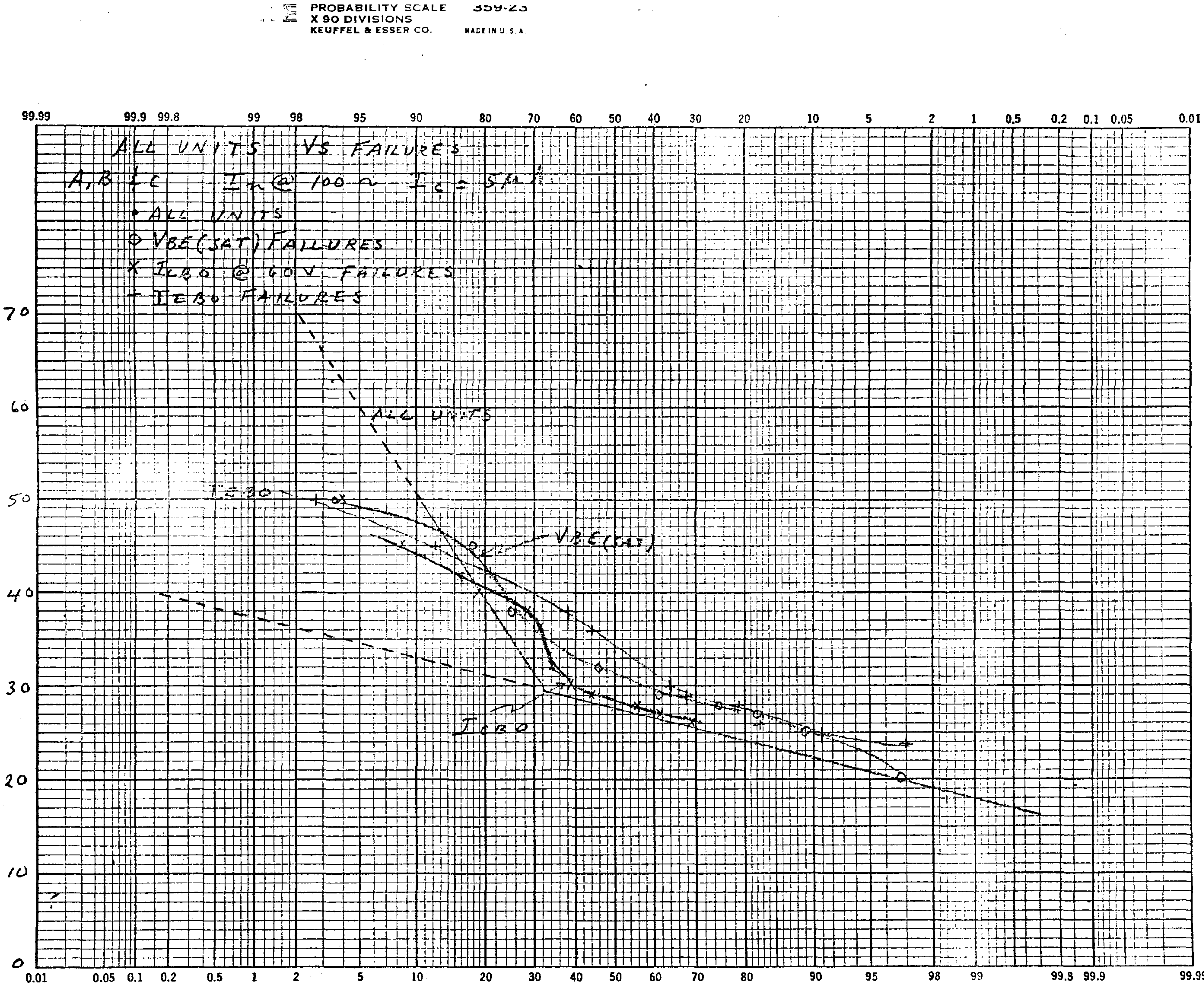

PROBABILITY SCALE 359-23
X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
ALL UNITS VS FAILURES
A,B & C I_n @ 100 V I_c = 5μA
• ALL UNITS
◇ VBE(SAT) FAILURES
× ICBO @ 60V FAILURES
+ IEBO FAILURES
ALL UNITS
IEBO
VBE(SAT)
ICBO
I_N IN PICOAMPERES
PERCENT OF UNITS AT OR ABOVE I_N

FIG. 4.8.1.2

4.8.2 Relation of noise to failure when noise is measured after the first step.

The effect of a noise mechanism which is activated by the first step is clearly whown by the change in the distribution of noise valves. This can be seen by comparison of Fig. 4.8.2.1 and 2 with 4.8.1.1 & 2.

Comparison of these curves show a clearer cause and effect relationship for most of the failure modes examined.

In the comparison of the noise of units prior to the first stress there were too few high noise units among the units which failed when this distribution is compared to the distribution of all units in the original sample.

This suggests a hypothesis that will require a more complete experiment with the data from phase II & III.

The mechanism which produces noise and degradation must have some operation of the transistor under stress such as voltage or voltage plus temperature before noise can be used as a predictor of reliability.

It is possible that the small amount of initial testing prior to the first test did act to partly activate this mechanism.

% of Failures Eliminated

IN -------	70	60	50	40	30	20	pA
% Yield	97.6	94.5	89.0	80.0	68.0	6.5	%
I_{CBO} @ 60V	11	20	32	46	60	98	%
I_{EBO}	19	29	41	54	72	97	%
BV_{CEO}	10	18	31	46	62	96	%
V_{CE} (SAT)	2	4	7	12	17	85	%
V_{BE} (SAT)	2	7	17	34	45	98	%
h_{FE}	7	14	25	40	56	96	%

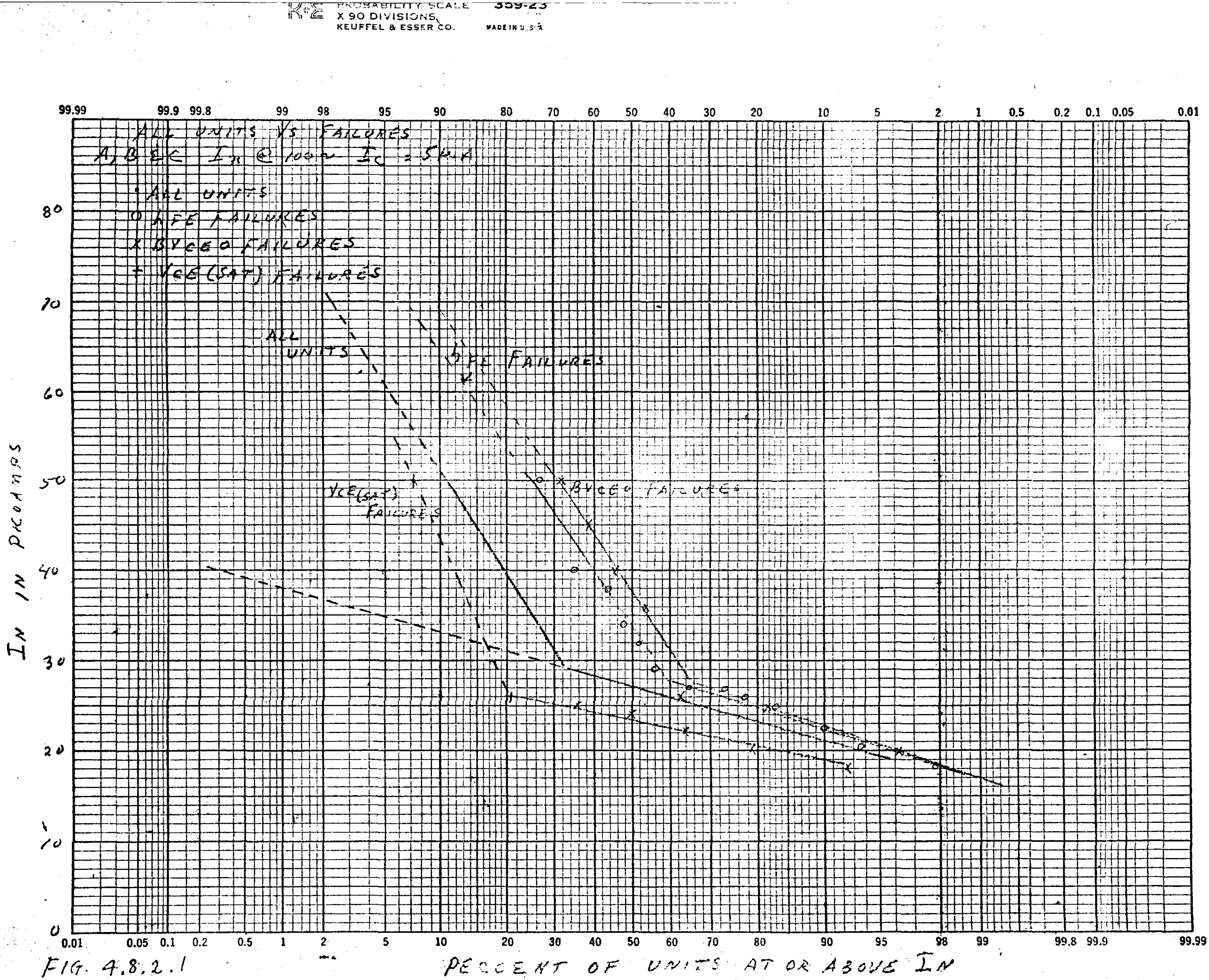

PROBABILITY SCALE 359-23
X 90 DIVISIONS
KEUFFEL & ESSER CO.
MADE IN U.S.A.
ALL UNITS VS FAILURES
A, B & C I_R @ 100V I_C = 5mA
• ALL UNITS
O hFE FAILURES
X BVCEO FAILURES
+ VCE(SAT) FAILURES
ALL UNITS
hFE FAILURES
BVCEO FAILURES
VCE(SAT) FAILURES
IN IN PICOAMPS
PERCENT OF UNITS AT OR ABOVE IN

FIG. 4.8.2.1

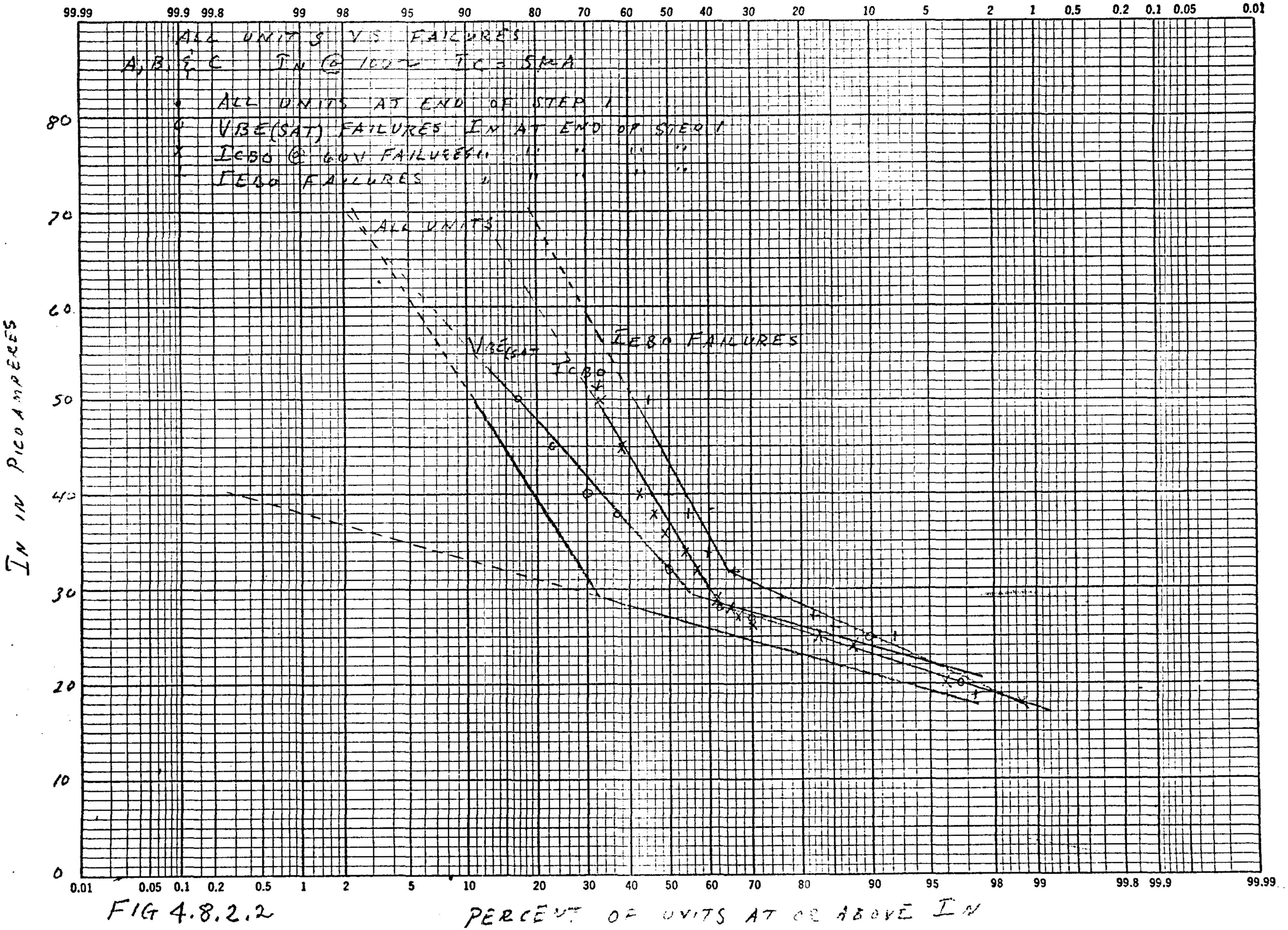

ALL UNITS VS FAILURES
A, B, & C I_N @ 100V I_C = 5mA
• ALL UNITS AT END OF STEP 1
○ VBE(SAT) FAILURES I_N AT END OF STEP 1
x ICBO @ 60V FAILURES " " " "
+ IEBO FAILURES " " " "
ALL UNITS
VBE(SAT)
ICBO
IEBO FAILURES
I_N IN PICOAMPERES
PERCENT OF UNITS AT OR ABOVE I_N

FIG 4.8.2.2

4.9 Conclusions

4.9.1 Limitations of the Analysis Method used.

The method of analysis used in the experiment is subject to several limitations which must be understood:

1. Use of a tighter than normal end of life limit did produce the effect of acceleration. The acceleration factor appropriate to the failure rates shown to failure rates under any other end point, is unknown. It undoubtedly differs for each process.

2. The mechanism which activates the noise prediction is also unknown. This experiment does not guarantee that all such mechanisms were fully activated.

4.9.2 Findings for device processes under study.

1. The experiment does show that there is a possibility that noise can be used as a predictor of reliability in a manner which will permit improvement of the reliability of the product.

2. The low frequency noise appears to be much more effective than other frequencies.

3. Measurement of noise appears much less effective on a new device than it is on a device after being stressed.

4.9.3 Work Unfinished

1. An inadequate number of failed units were on hand to identify differences in results for the three processes separately. The more detailed experiment in Phase II and III should provide substantially more information because more failures of each classification will be available.

2. Study of the "noise activation" processes is necessary. Use of noise tests as an intermediate step in a stress - screening method will probably be effective. However, a short period stress, (voltage, or voltage-temperature) may be equally effective. This will be identified further.

3. Noise develops during degradation. However, if the transistor action drops (h_{FE} decrease), the noise indication will drop off. This effect may be concealing some of the statistical effects of noise. Further investigation will be conducted on the larger sample to determine the effect of noise independent of other failure indicators.

4.9.3 Cont.

4. In failure analysis, it was found that noise was higher on units with surface degradation. These units are recoverable in terms of leakage. A more detailed study will be made to determine if the noise is recoverable in a direct relation to the amount the surface is recoverable.

   It is possible that noise which may remain after the surface recovers will provide an important clue to the noise vs. degradation relationship.

5. Process B data analysis shows a possibility that noise is related to degradation of the bonding at the post. If enough of such failures are found in the phase III, a controlled experiment to establish this relationship will be possible.

6. Several other facts have been noted in the preliminary study of noise vs failure mechanism. This work was incomplete at end of second quarter and will be included in the 3rd. Quarter Report.

5.0 Phase II Screening Experiment

The effect of the screening experiment is included on a preliminary basis only. This report covers the percentages lost on each lot and to three sets of limits.

The percentage failure at 300°C for process C is not as great as expected from the initial step stress experiment.

This shows a total failure of 53%. Previous estimates had placed this higher.

Some serious destruction may occur from the 25 KG centrifuge on the Process C units however.

5.1 Brief review of observed results on Phase II.

There are several other interesting details present from this data.

1. Process B units do not seem to increase in percentage failures when a 300°C bake is used over a 200°C bake. Process A has a sharp increase in percentage failures from 1.2 to 13.3 percent. Process B shows 12 percent at either condition. The Al-Al bonding may account for no temperature differences but failures are due to some other mechanisms.

2. Process C units seem to be usually good at the first step 250°C plus 30 volts. This indicates their dominant failure mechanism is not similar to the other failure mechanisms.

   The characteristic failure of Process C units seems to be cracks in the silicon under the bond. This mechanism may not develop at the 250°C level.

5.2 Explanation of Tablulated Results.

Fig. 5.2.1 shows the tabulated data for all failures in the phase II experiment. These are expressed in percentages.

Failures were chosen as units which exceeded three separate sets of limits of 1, 10, and 100X for leakage and initial. Initial ± 10% and Initial ± 20% for three levels as follows:

LEVEL	1	2	3
I_{CBO} @ 60V	10 nA	100 nA	1 mA
I_{EBO} @ 5V	10 nA	100 nA	1 μA
BV_{CEO}	32 V	29 V	26 V
h_{FE} Min.	35	31.5	28
Max.	150	165	180

FIG. 5.2.1

PERCENT REJECTED TO (1) INITIAL (2) END OF LIFE (3) CATASTROPHIC

Limits at Initial Test, First Step T + V 3rd. Step Voltage

TEST NO. (STRESS 1)	TOTAL UNITS (STRESS 2)	PROCESS	LIMIT	INITIAL (5 MO. STORAGE)					AFTER FIRST STRESS					AFTER SECOND STRESS				
				I_{CBO}	I_{EBO}	BV_{CEO}	h_{FE} MIN	h_{FE} MAX	I_{CBO}	I_{EBO}	BV_{CEO}	h_{FE} MIN	h_{FE} MAX	I_{CBO}	I_{EBO}	BV_{CEO}	h_{FE} MIN	h_{FE} MAX
404101 (250 C + 30V)	165 Units (300 C)	A	(1)	0	0	0	0	0	0	0	0	0	0	3.0	.6	0	0	0
			(2)	-	-	-	-	-	0	.6	0	0	0	4.9	.6	0	0	0
			(3)	-	-	-	-	-	0	0	0	0	0	3.0	0	1.2	0	0
404102 (250 C + 30V)	165 Units (200 C)	A	(1)	0	0	0	0	0	0	0	0	0	0	.6	0	0	0	0
			(2)	-	-	-	-	-	0	0	0	0	0	.6	0	0	0	0
			(3)	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0
404103 Centrifuge	85 Units	A	(1)	0	0	0	0	0	0	0	0	0	0					
			(2)	-	-	-	-	-	0	0	0	0	0					
			(3)	-	-	-	-	-	0	0	0	0	0					
404104 (No Stress)	80 Units	A	(1)	0	0	0	0	0										
			(2)	-	-	-	-	-										
			(3)	-	-	-	-	-										
404105 (250 C + 30V)	165 Units (300 C)	B	(1)	0	0	*.6	0	.6	0	7.9	0	0	0	3.0	8.5	0	0	0
			(2)	-	-	-	-	-	0	.6	0	0	0	0	0	0	0	0
			(3)	-	-	-	-	-	0	0	0	0	0	.6	0	0	0	0
404106 (250 C + 30V)	165 Units (200 C)	B	(1)	0	0	0	0	0	0	5.4	0	0	**.6	3.0	5.5	0	0	0
			(2)	-	-	-	-	-	0	0	0	0	0	.6	0	0	0	0
			(3)	-	-	-	-	-	0	0	0	0	0	1.8	.6	0	1.2	0
404107 (Centrifuge)	85 Units	B	(1)	0	0	0	1.2	0	0	4.7	0	0	0					
			(2)	-	-	-	-	-	0	0	0	0	0					
			(3)	-	-	-	-	-	0	0	0	0	0					
404108 No Stress	80 Units	B	(1)	0	1.2	0	0	0										
			(2)	-	-	-	-	-										
			(3)	-	-	-	-	-										

FIG. 5.2.1 (CONT.)

TEST NO. (STRESS 1)	TOTAL UNITS (STRESS 2)	PROC-ESS	LIMIT	INITIAL (5 MO. STORAGE) I_{CBO}	IEBO	BV_{CEO}	h_{FE} MIN	h_{FE} MAX	AFTER FIRST STRESS I_{CBO}	I_{EBO}	BV_{CEO}	h_{FE} MIN	h_{FE} MAX	AFTER SECOND STRESS I_{CBO}	I_{EBO}	BV_{CEO}	h_{FE} MIN	h_{FE} MAX
404109 (250 C + 30V)	60 Units (300 C)	C	(1)	6.7	0	0	0	0	0	0	0	0	0	5.0	1.7	0	0	0
			(2)	-	-	-	-	-	0	0	0	0	0	16.7	0	0	0	0
			(3)	-	-	-	-	-	0	0	0	0	0	20.0	0	8.3	0	1.7
404110 (250 C + 300)	203 Units (200 C)	C	(1)	3.4	0	0	0	.5	.5	0	0	0	0	6.9	0	0	0	0
			(2)	-	-	-	-	-	.5	0	0	0	0	4.9	0	0	0	.5
			(3)	-	-	-	-	-	0	0	0	0	0	12.8	0	8.9	0	0
404111 (Centrifuge)	120 Units	C	(1)	2.5	0	0	0	0	0	.8	0	0	0					
			(2)	-	-	-	-	-	0	0	0	0	0					
			(3)	-	-	-	-	-	0	0	0	0	0					
404112 No Stress	118 Units	C	(1)	2.5	0	0	0	0										
			(2)	-	-	-	-	-										
			(3)	-	-	-	-	-										

* h_{FE} failed also, but not counted as h_{FE}.

** Unit recovered.

5.3 Overall Results (Drop Out)

Fig. 5.3.1 shows the combined percentage failures to initial limits only. This table assumes that screening limits would not be increased over the initial limits used in the specification.

FIG. 5.3.1

OVERALL EFFECTS OF FIRST 3 TESTS OF PHASE 2

TEST	PROCESS	% FAILURE
1. 5 Months Storage	A	0
	B	.7
	C	3.9
2. 250°C + 30V	A	.3
	B	7.0
	C	1.0
3. 300°C after 2	A	13.3
	B	12.1
	C	53.4
4. 200°C after 2	A	1.2
	B	12.7
	C	24.6
5. Centrifuge @ 25 ~~KG~~	A	0
	B	4.7
	C	.8

Centrifuge at 25 KG following the Step 2 was not completed as of March 31, 1964 and will be reported later.